Caring without Borders

Espnic 2013
June 12-15, 2013
Rotterdam, Netherlands

Society of Paediatric and Neonatal Intensive Care

Faculty Disclosure

	No, nothing to disclose
X	Yes, please specify:

Company Name	*Honoraria/ Expenses*	*Consulting/ Advisory Board*	*Funded Research*	*Royalties/ Patent*	*Stock Options*	*Equity Position*	*Ownership/ Employee*	*Other (please specify)*
Maquet	X	X		X				

Off-Label Product Use

Will you be presenting or referencing off-label or investigational use of a therapeutic product?	
X	No
	Yes, please specify:

Physiological Concepts Behind Neurally Adjusted Ventilatory Assist (NAVA) and Non-Invasive NAVA (NIV-NAVA)

Jennifer Beck, PhD
Keenan Research Center at the Li Ka Shing Knowledge Institute of St. Michael's Hospital, Toronto
Department of Pediatrics, University of Toronto

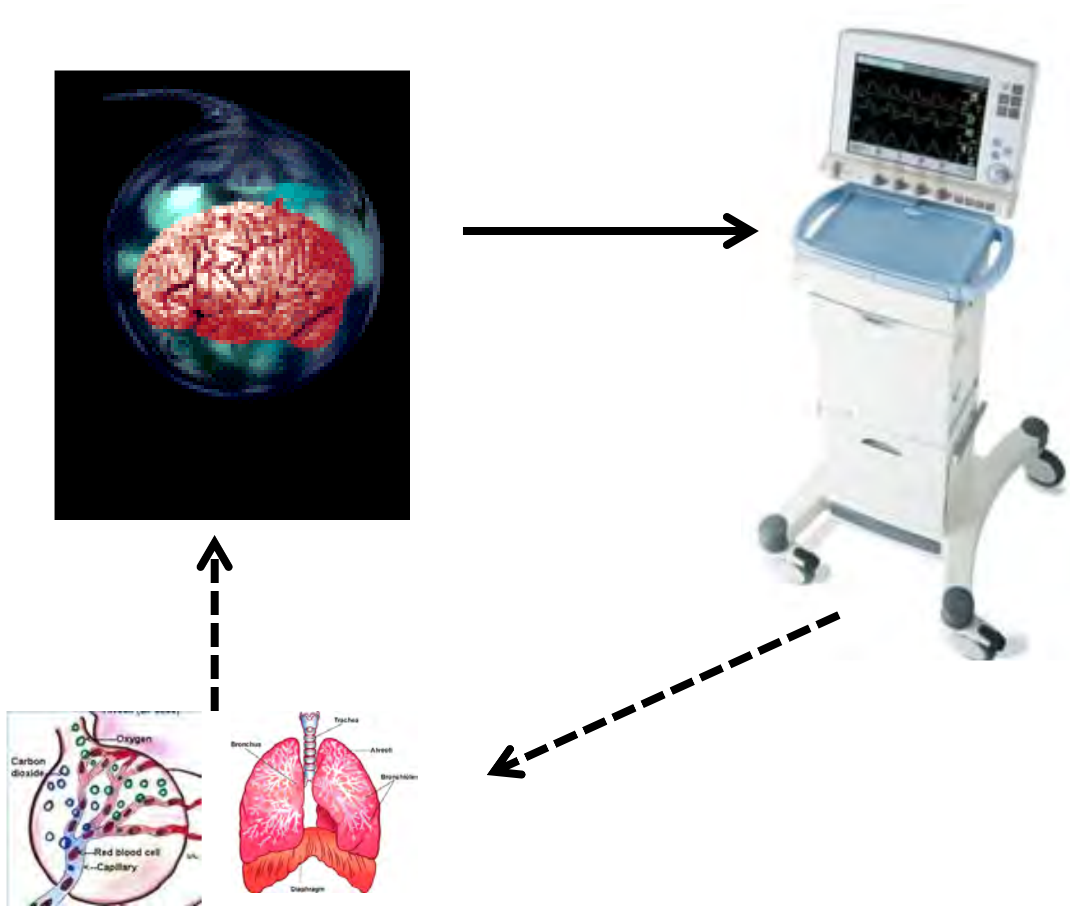
- www.VentQuest.ca

- Jennifer.beck@rogers.com

Neural Control of Artificial Muscles

Jan 2010 *Time Magazine Jan 2008 (European Ed)*

Neurally Controlled Mechanical Ventilation

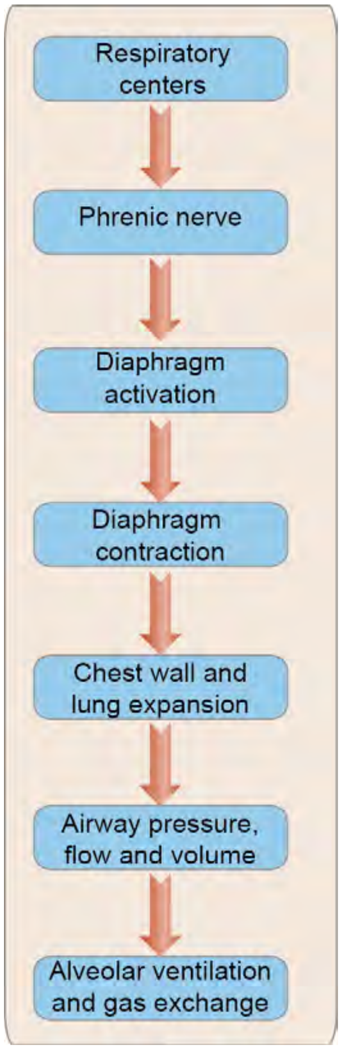


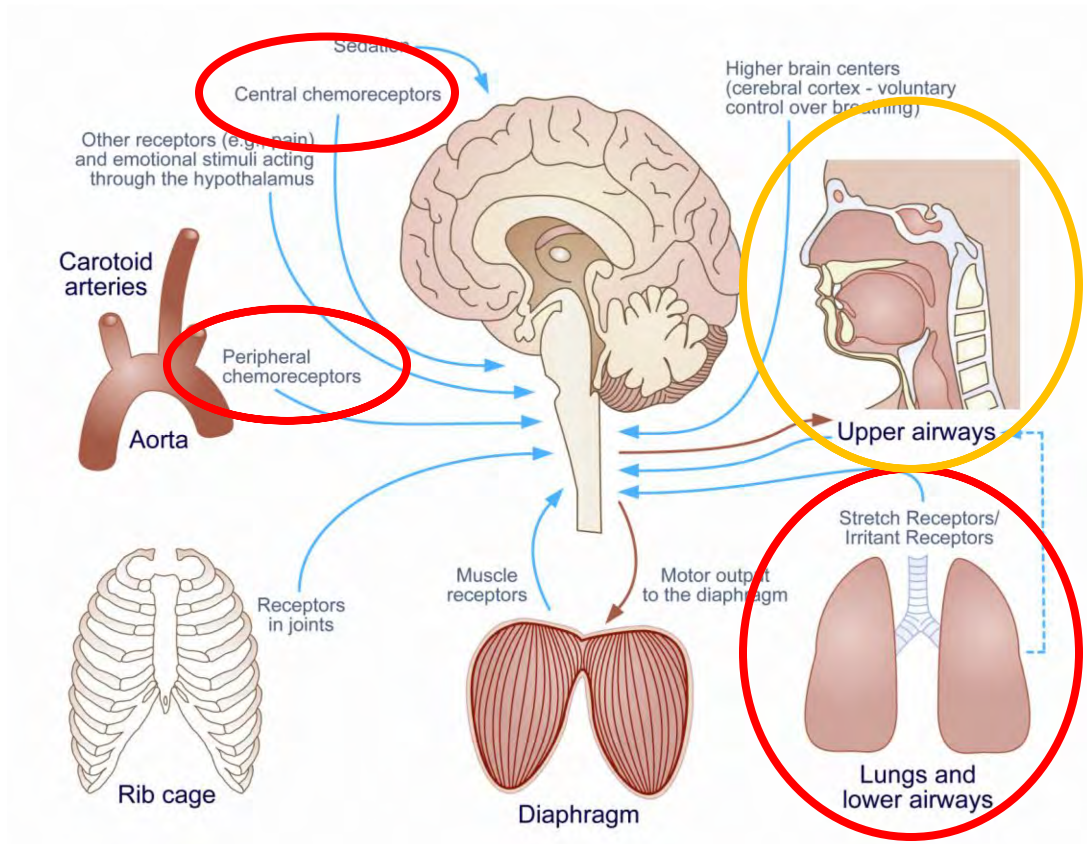
Unique Features about Infants

- Surfactant deficiency and compliant chest wall make that the lung has a tendency to de-recruit
- Strong vagal reflexes
- Apnea of prematurity
- Uncuffed ET tubes

“Maggie” 500 g at birth (with permission from the parents)

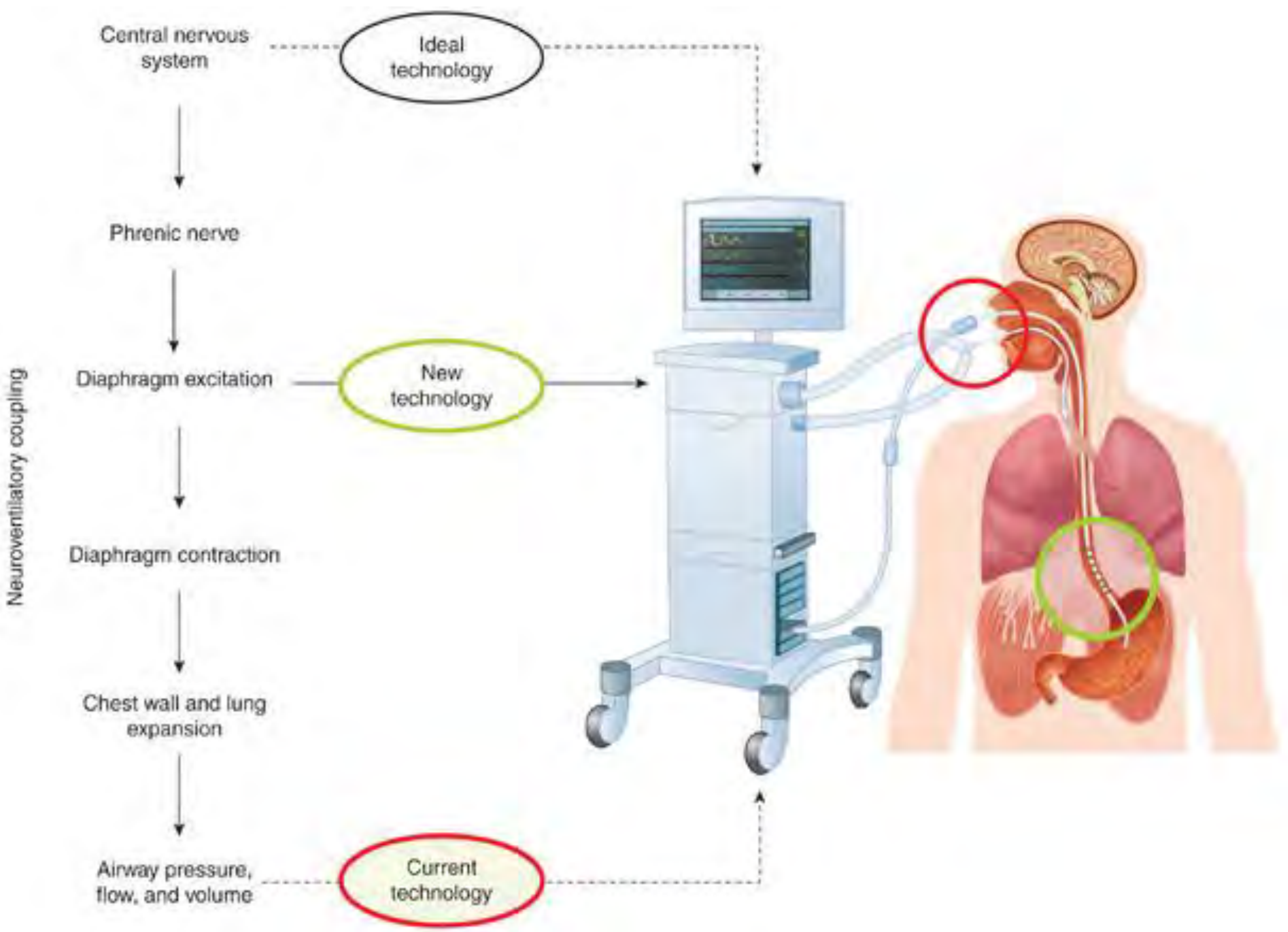
Breathing is Neurally Regulated





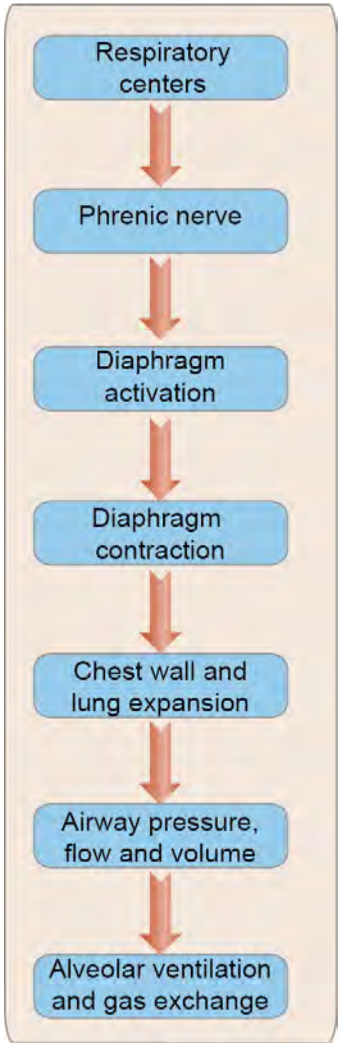
Principles and Practice of Mechanical Ventilation, M Tobin Ed. 2012

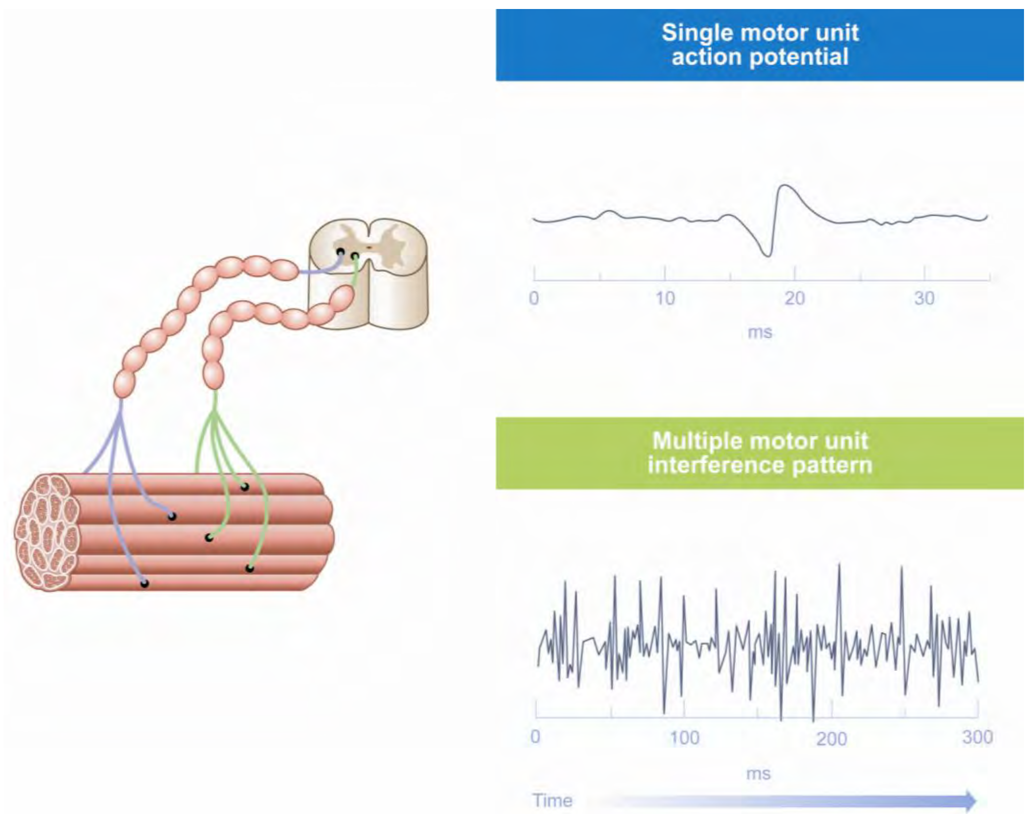
General Principles of NAVA



Sinderby & Beck, Neurally Adjusted Ventilatory Assist in Principles and Practice of Mechanical Ventilation, Third Edition Editor: Tobin MJ, McGraw-Hill Medical 2012

EMG of Skeletal Muscle

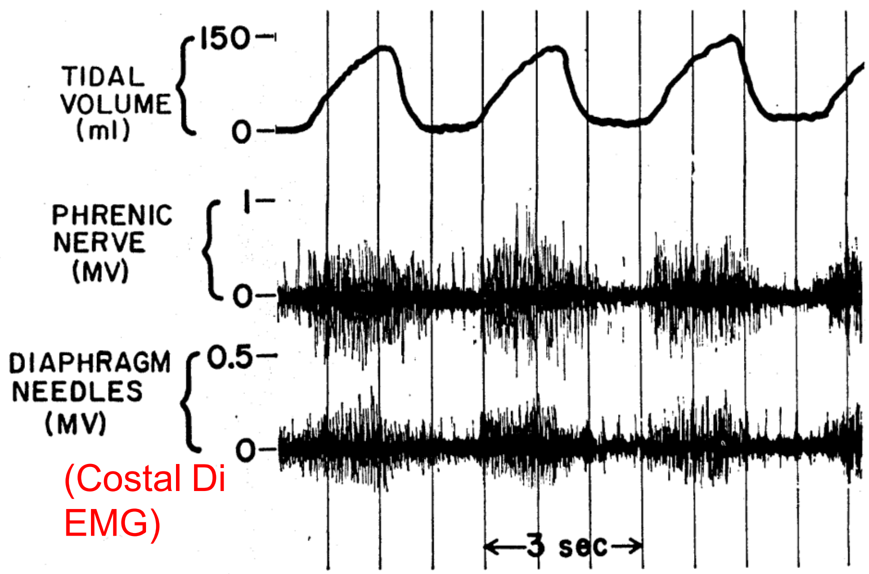


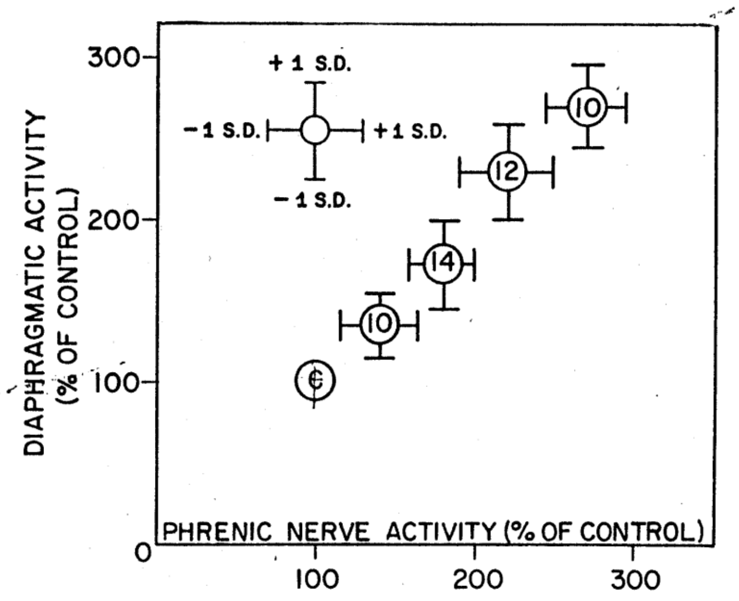


"EMG"

Principles and Practice of Mechanical Ventilation, M Tobin Ed. 2012

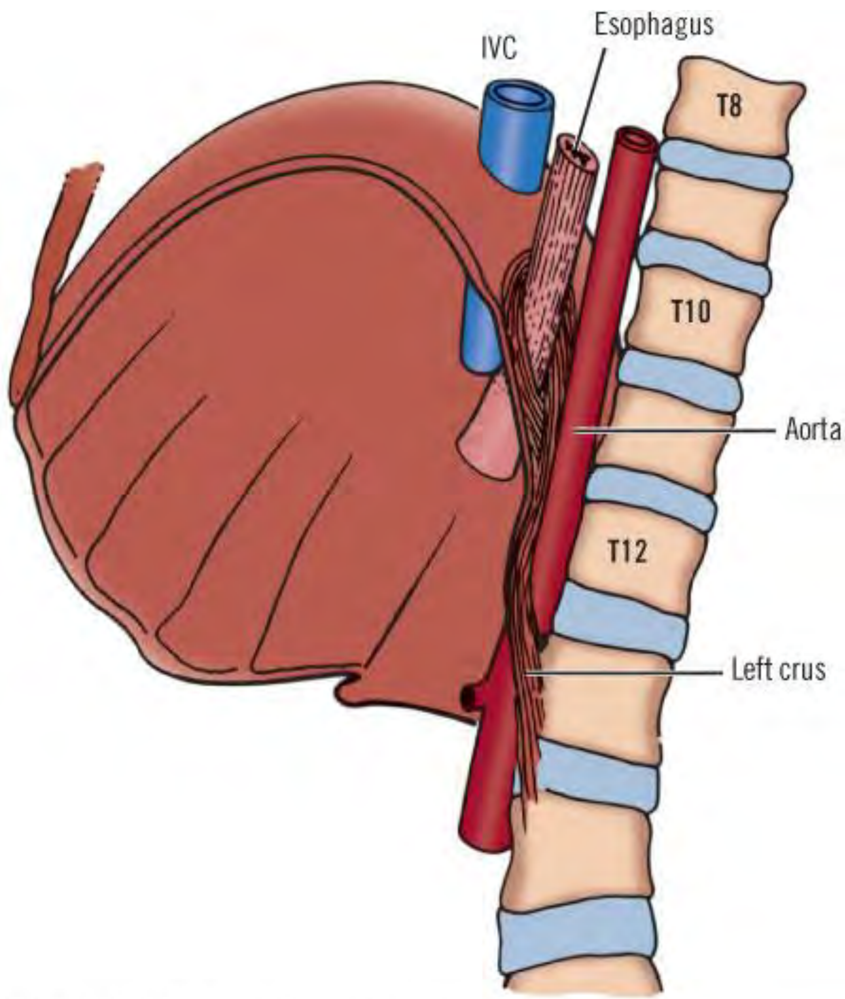
EMG is the Neural Drive to the Diaphragm



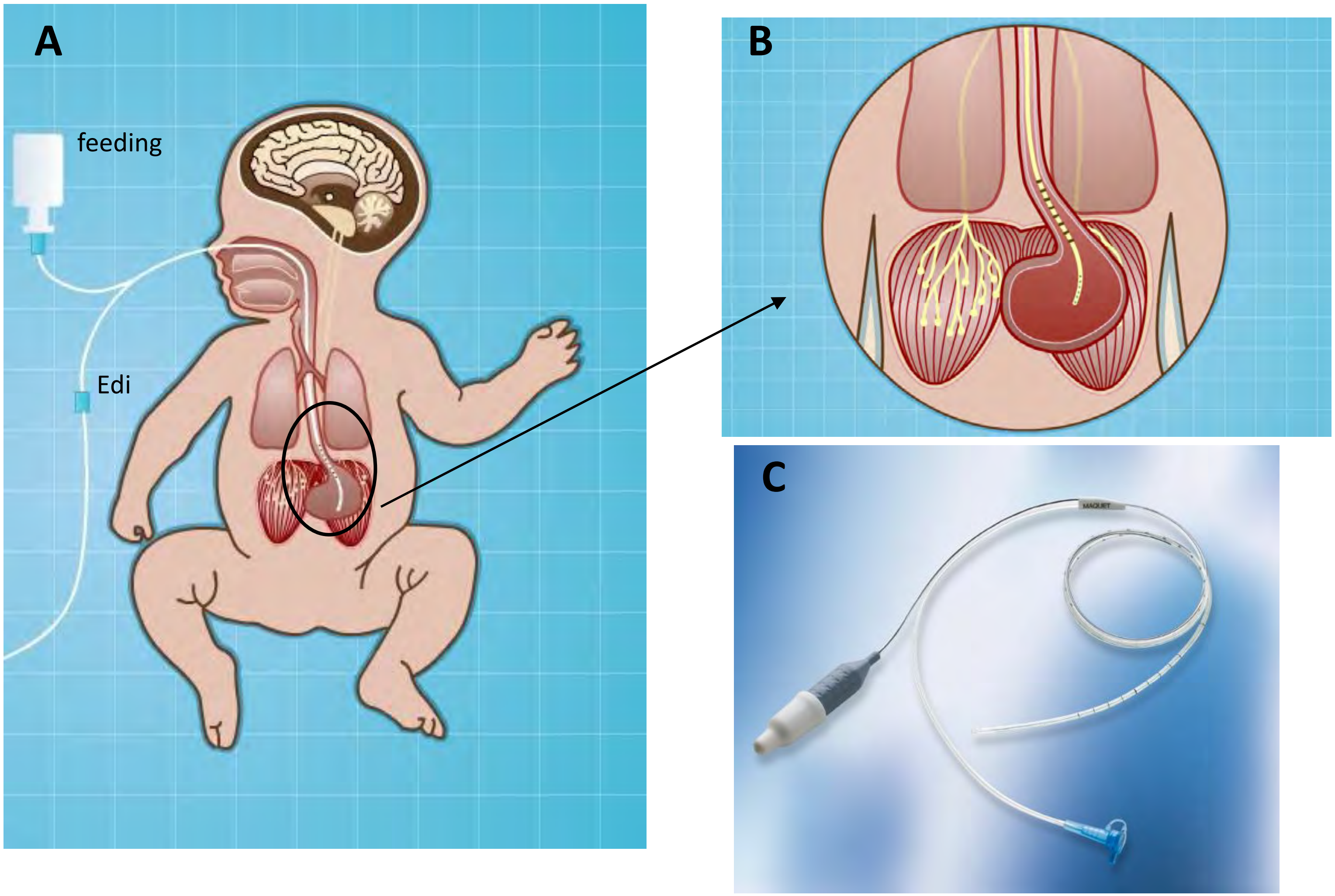


Lourenco et al, J. Appl. Physiol. 1966.

How to Measure Diaphragm EMG in Humans?



Modified Feeding Tube



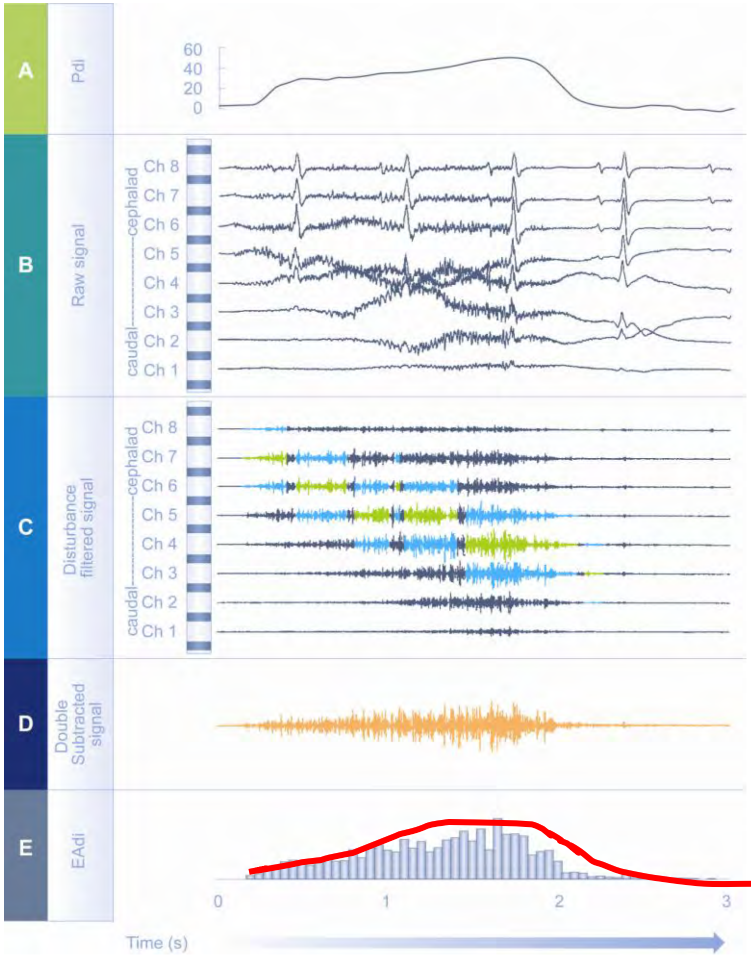
Electrode Positioning

- NEX
- Calculate prediction
- Insert to prediction
- Positioning window (verification)
- Secure and record final position

Validation studies:

Barwing, ICM (2009); Green, Respir Care (2011); Barwing, ICM (2011); Duyndam, Nursing in Crit Care (2013); Stein, J Perinatology (2013), Vignaux, PCCM, In Press (2013)

EMG to Edi Waveform

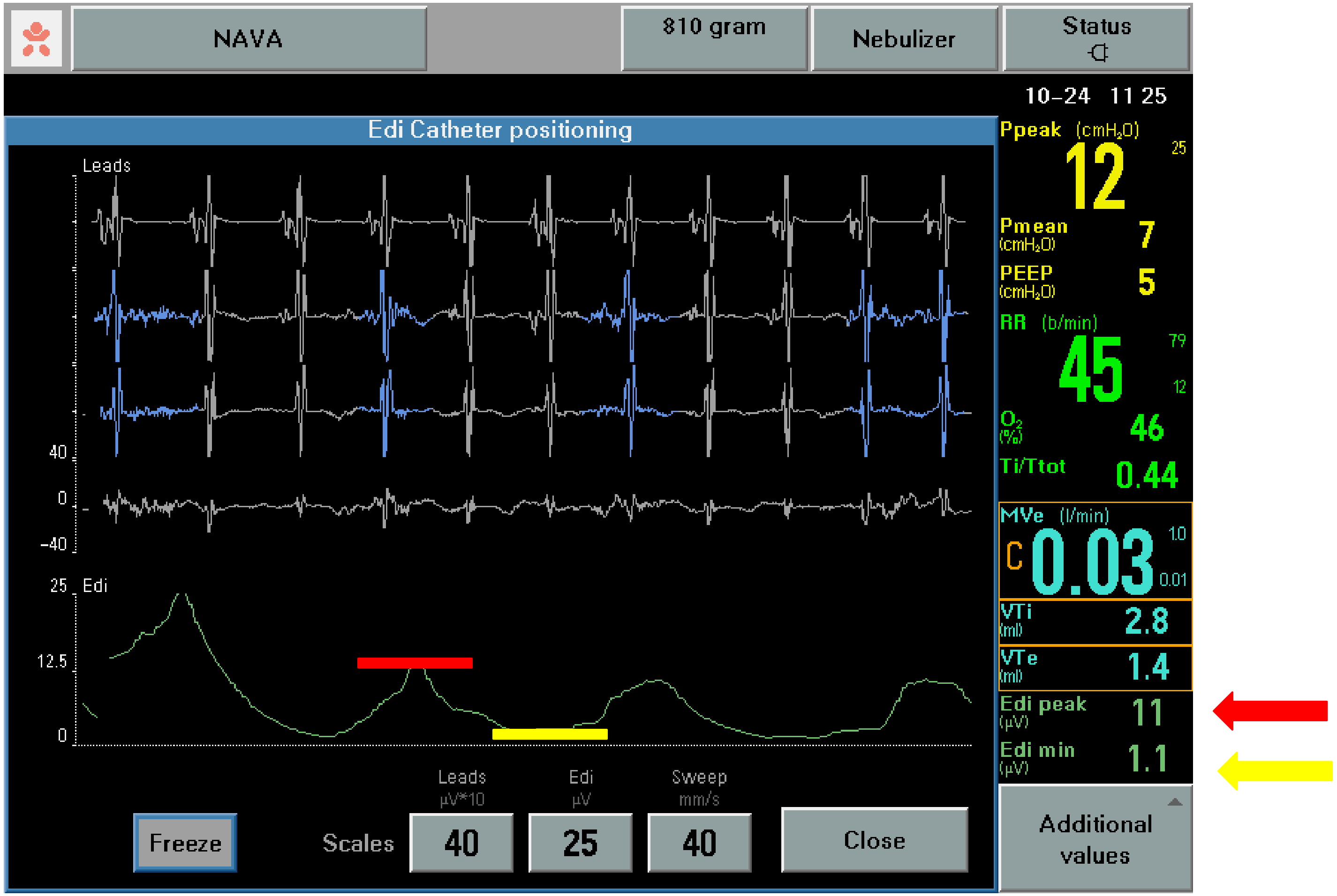


Principles and Practice of Mechanical Ventilation, M Tobin Ed. 2012

Edi waveform

4 leads

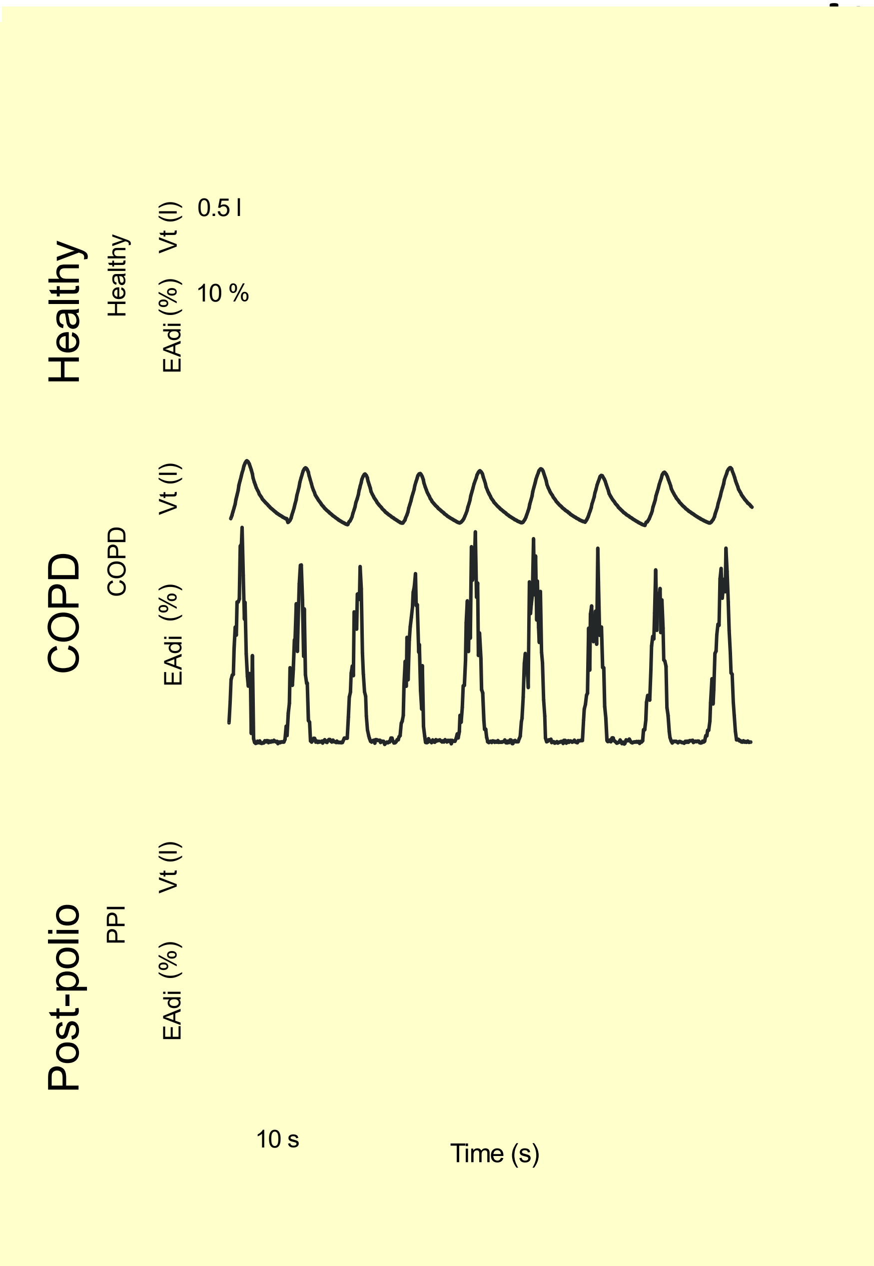
Edi



Edi in Infants and Adult

Principles and Practice of Mechanical Ventilation, M Tobin Ed.

peak



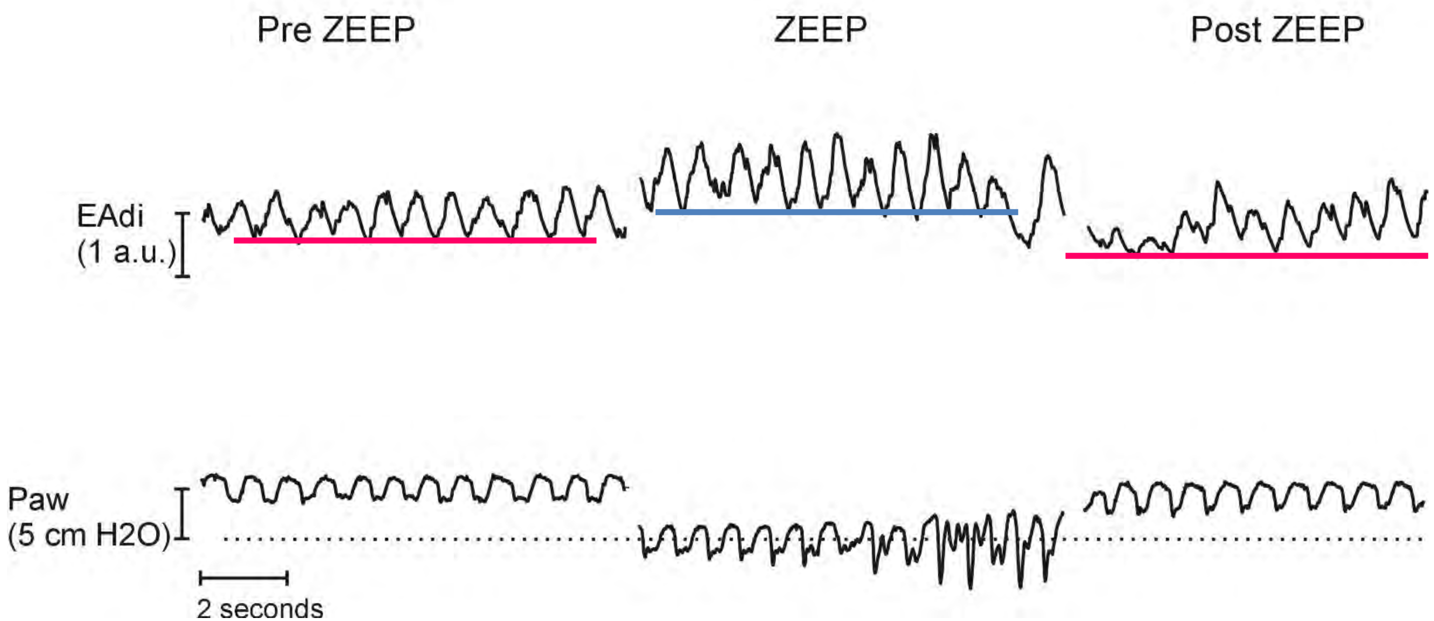
- Reduced level of assist
- Increased Respiratory Load
- Weakness of Diaphragm
- Increased CO_2
- Reduced sedation

Published Edi_{pk} (on Servoi)

Catheter size	Condition	Mean Edipk (uV)	Lowest mean value Edi pk (uV)	Highest mean value Edi pk (uv)	# studies	# patients
16	Intubated on NAVA	10.4	4	15	16	204
16	NIV-NAVA	19.2	11	33	4	53
8	Intubated on NAVA	9.1	5	11	4	44
8	*NIV-NAVA*	*27*	*20*	*34*	*2*	*15*
6	Intubated on NAVA	9.4	7.4	11.4	3	47
6	NIV-NAVA				0	0
6	No assist	11	10	16	1	3 (healthy)
ALL		13.8	4	34	34	507

Revised June 9, 2013

Edi_{min}



Emeriaud et al, Ped Res, 2006

- De-recruitment below FRC
- Liquid/edema in the lung
- ??

0031-3998/11/7006-0607
PEDIATRIC RESEARCH

Vol. 70, No. 6, 2011
Printed in U.S.A.

Characterization of Neural Breathing Pattern in Spontaneously Breathing Preterm Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASSELLI, HAIBO QUI, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER A. SINDERBY

Pediatr Res 70: 607–613, 2011

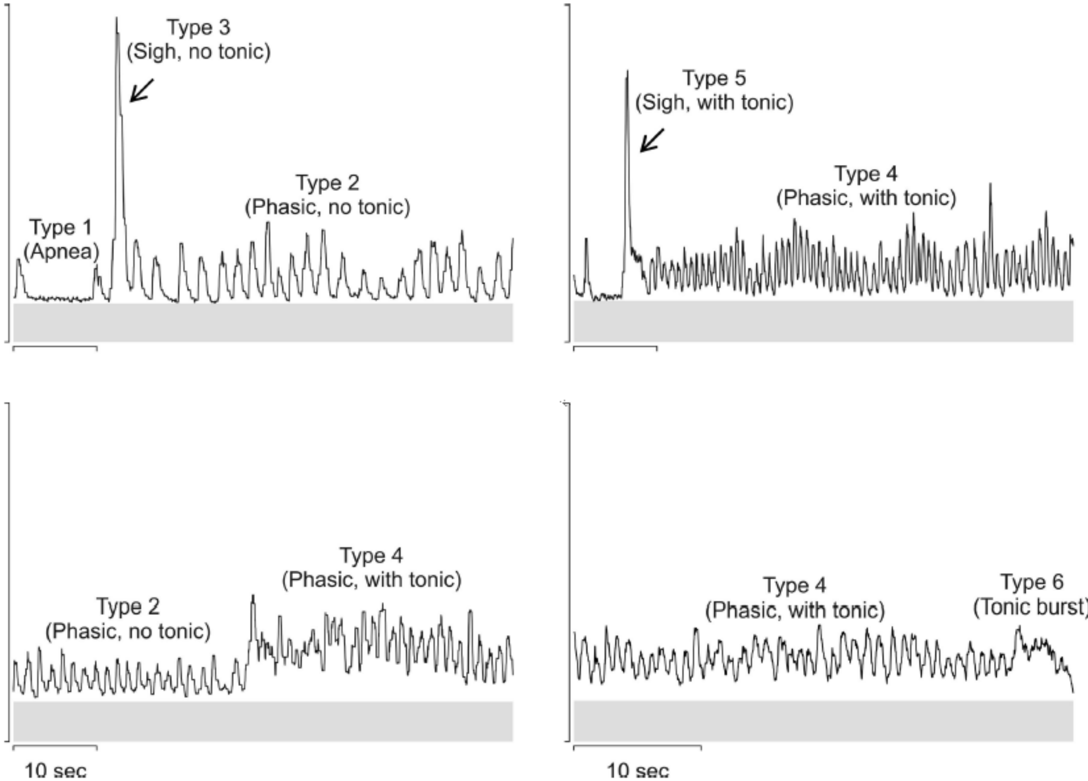
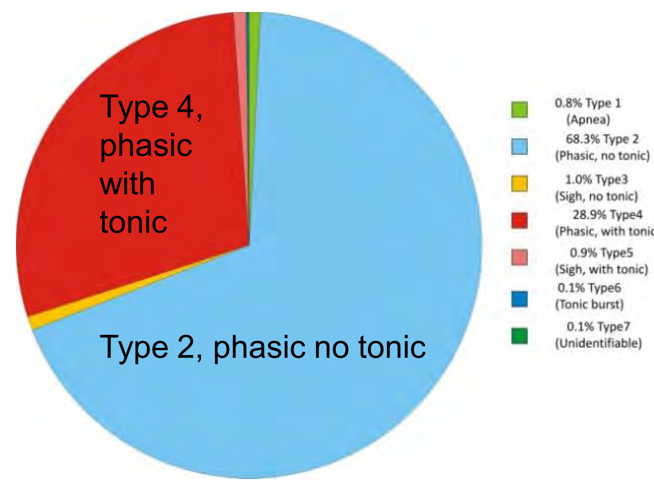


Figure 4. Representative tracings of the different neural breathing patterns on the same day: each panel demonstrates the EAdi waveform obtained in one subject on the same recording day, and demonstrates examples of the different breathing pattern types (1–7, see Methods).



N = 10
Mean weight = 1400 g
Mean age = 8 days
GA at birth: 31 wks

Characterization of Neural Breathing Pattern in Spontaneously Breathing Preterm Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASSELLI, HAIBO QUI, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER A. SINDERBY

Pediatr Res 70: 607–613, 2011

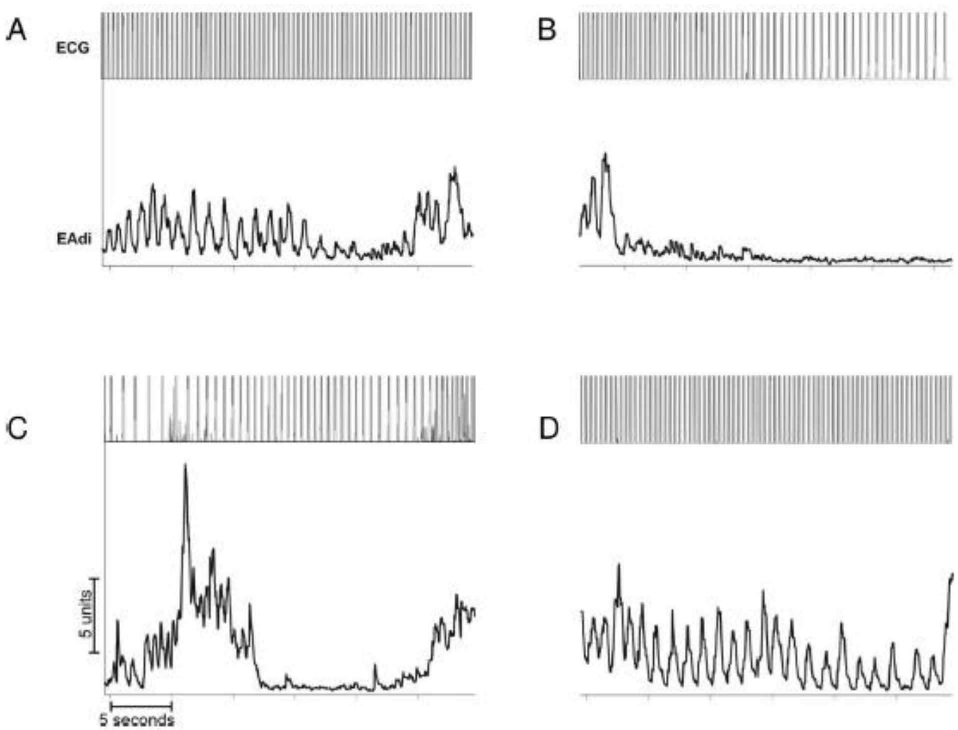


Figure 6. Representative tracings of EAdi and ECG in one subject: time sequence is Figure 6*A* to *D*. Each panel demonstrates the EAdi waveform (bottom in each panel) and the ECG. (*A*) = 30 s before the apnea, heart rate was 153, and saturation 98%. (*B*) = slowing in heart rate at the same time as the central apnea. (*C*) = Heart rate 66, saturation 82%, and the nurse aroused the baby (*D*). Three minultes later, HR = heart rate 159 and saturation = 99%.

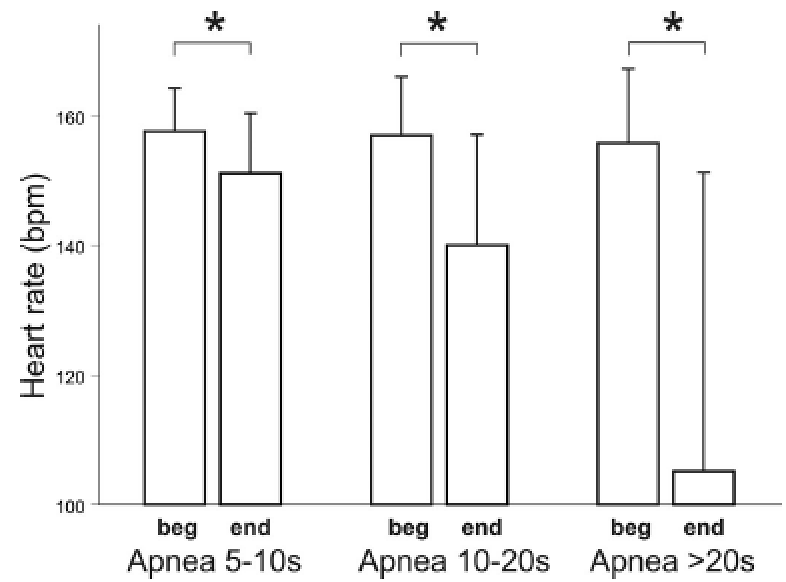


Figure 7. Relationship between central apnea duration and heart rate: group data demonstrating that longer apneas are associated with greater reductions in heart rate. *Statistical significance from beginning to end of apnea.

N = 10
Mean weight = 1400 g
Mean age = 8 days
GA at birth: 31 wks

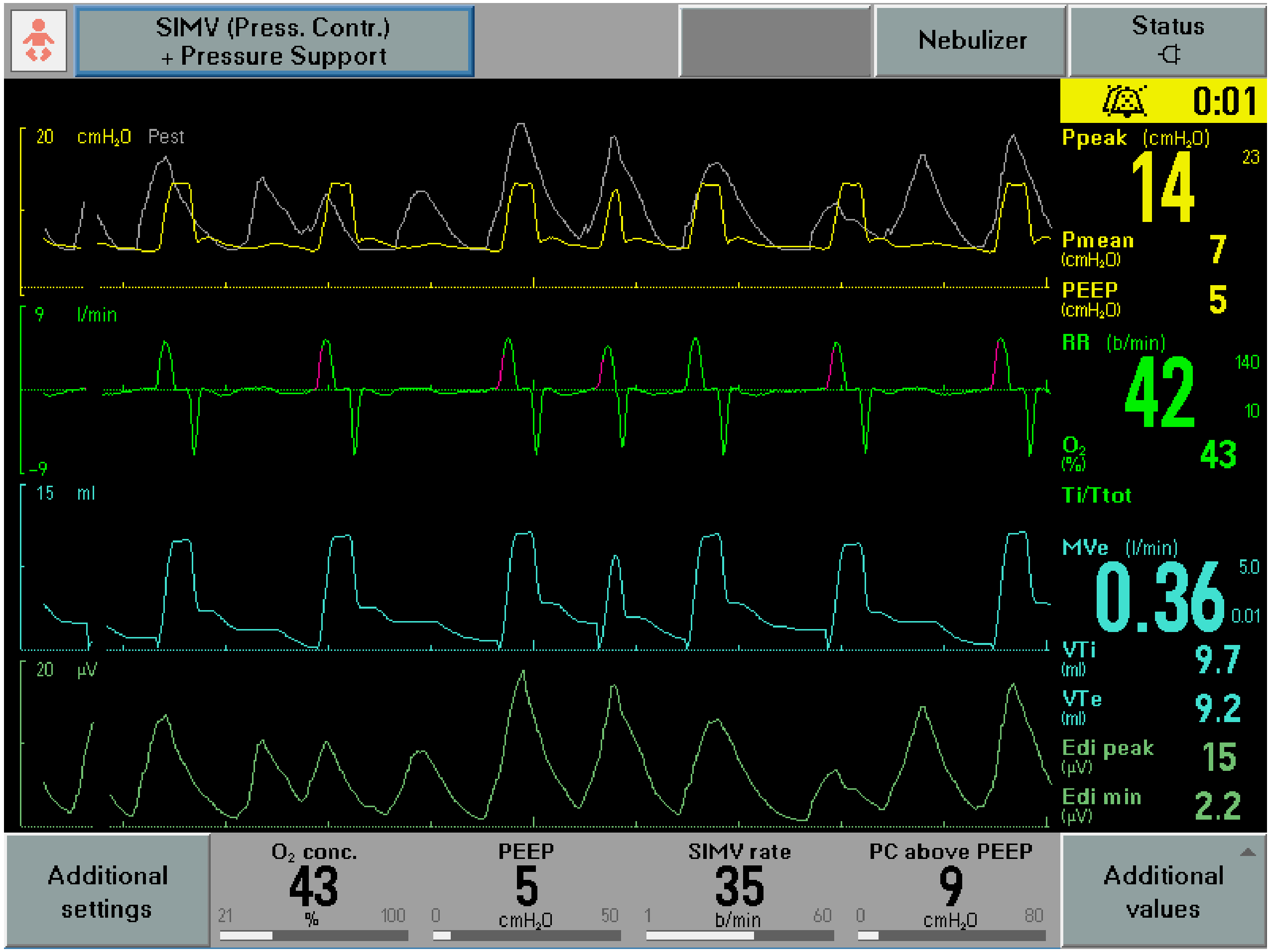
Edi and Patient-ventilator Interaction

Pvent

Flow

Volume

Edi



Slide Courtesy of H Stein, Toledo Children's Hosp.

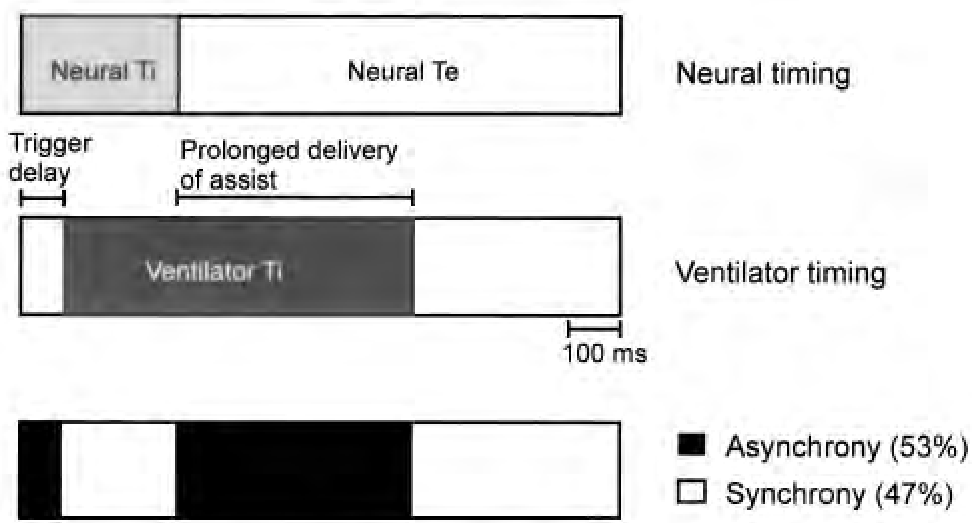
0031-3998/04/5505-0747
PEDIATRIC RESEARCH

Vol. 55, No. 5, 2004
Printed in U.S.A.

Prolonged Neural Expiratory Time Induced by Mechanical Ventilation in Infants

JENNIFER BECK, MARISA TUCCI, GUILLAUME EMERIAUD, JACQUES LACROIX, AND CHRISTER SINDERBY

Pediatric Intensive Care Unit, Department of Pediatrics and Hôpital Sainte-Justine Research Center, Université de Montréal, Montreal, Quebec H3T 1C5 [J.B., M.T., G.E., J.L.]; Department of Newborn and Developmental Pediatrics, Sunnybrook and Women's College Health Sciences Centre, Toronto, Ontario M5S 1B2 [J.B.]; and Department of Critical Care Medicine, St-Michael's Hospital, Toronto, Ontario M5B 1W8 [C.S.], Canada



N = 14
Mean weight = 3.9 kg
Mean age = 2.3 mos

Figure 4. Patient–ventilator interaction during mandatory breaths. Schematic representation of patient neural timing (*upper bar*) and ventilator timing (*middle bar*) during mandatory breaths. *Upper bar*, neural Ti (*gray area*) and neural Te (*white*) for the group data are presented. *Middle bar*, periods describing ventilator timing are displayed, including trigger delay and ventilator Ti. *Bottom bar*, periods of infant–ventilator synchrony (*white*) and asynchrony (*black*).

Excellent Reference on Edi Monitoring

Hindawi Publishing Corporation
Critical Care Research and Practice
Volume 2013, Article ID 384210, 7 pages
http://dx.doi.org/10.1155/2013/384210

Review Article

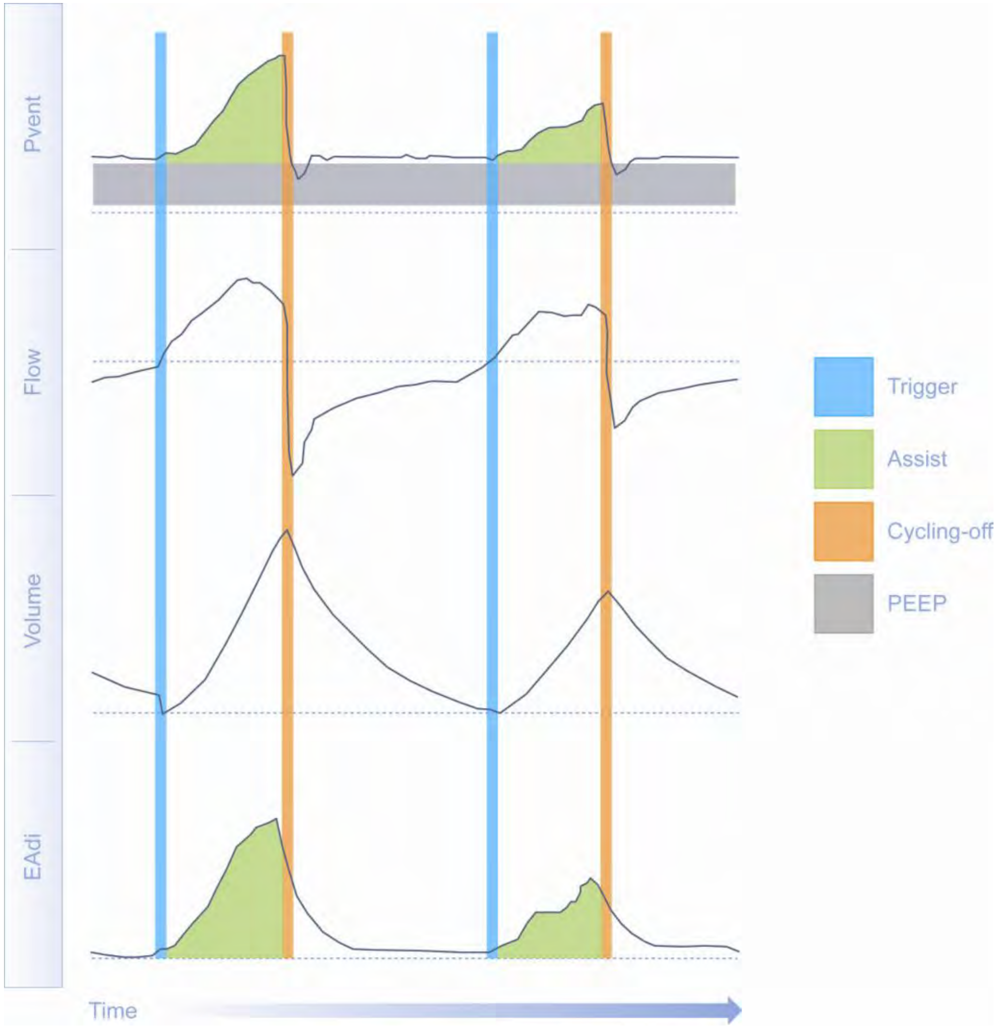
Interest of Monitoring Diaphragmatic Electrical Activity in the Pediatric Intensive Care Unit

Laurence Ducharme-Crevier, Geneviève Du Pont-Thibodeau, and Guillaume Emeriaud

Pediatric Intensive Care Unit, CHU Sainte-Justine, Université de Montréal, 3175 Chemin de la Côte Sainte-Catherine, Montreal, QC, Canada H3T 1C5

Correspondence should be addressed to Guillaume Emeriaud; guillaume.emeriaud@umontreal.ca

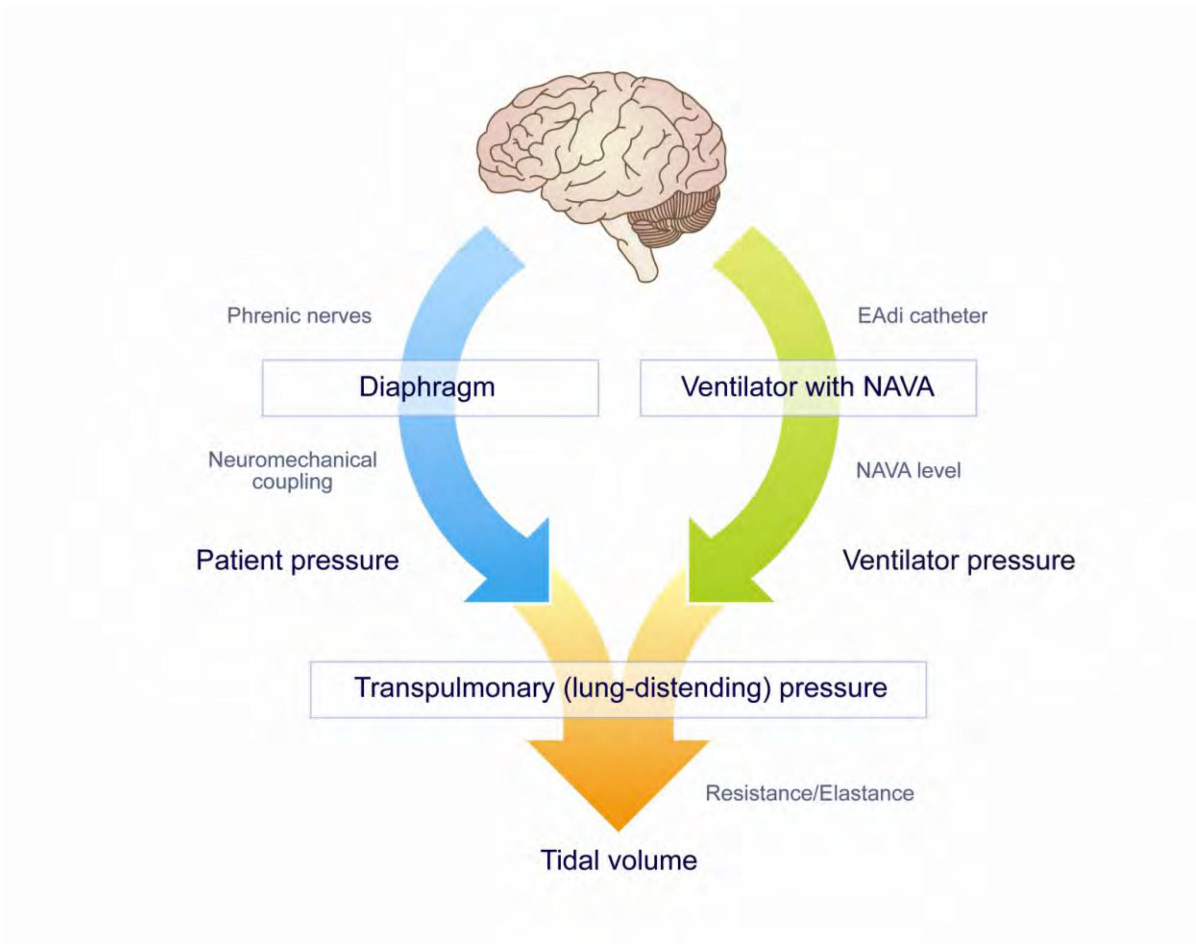
Edi and Controlling Mechanical Ventilation: NAVA

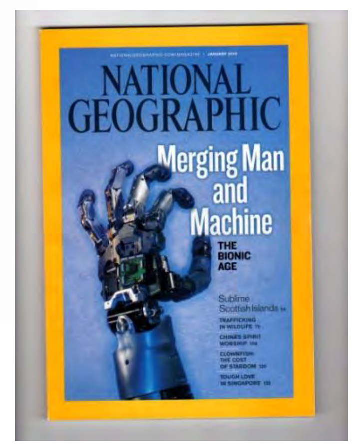


Upper pressure limits
Backup ventilation

Principles and Practice of Mechanical Ventilation, M Tobin Ed. 2013

NAVA is an Artificial Respiratory Muscle

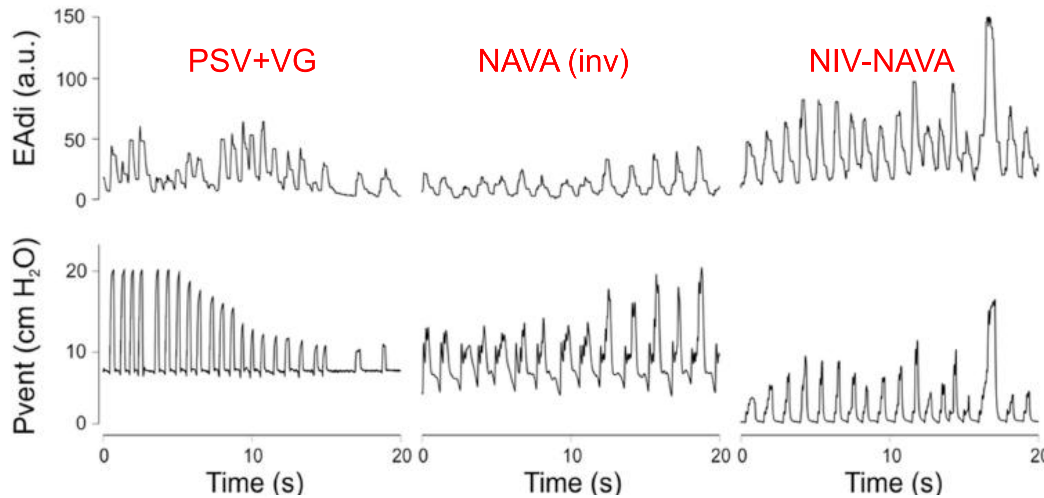


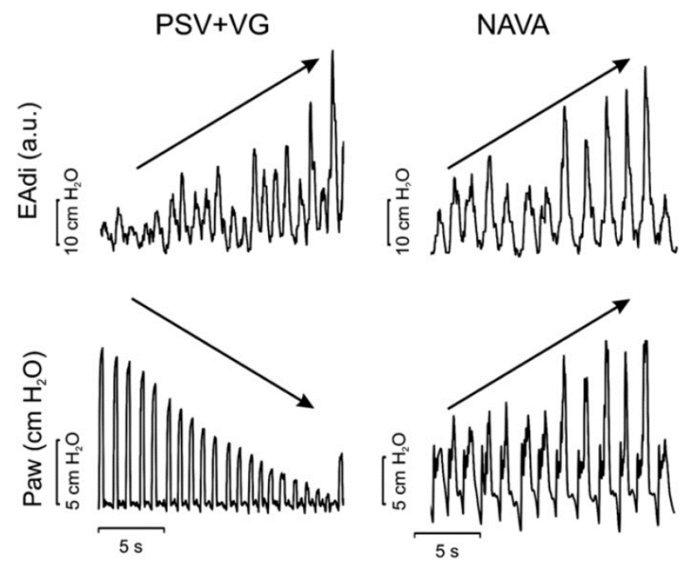


Patient-Ventilator Interaction During Neurally Adjusted Ventilatory Assist in Low Birth Weight Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASSELLI, LUCIA MIRABELLA, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER SINDERBY

(*Pediatr Res* **65: 663–668, 2009**)





N = 7
Mean weight = 976 g
Mean age = 12 days
GA at birth: 26 wks

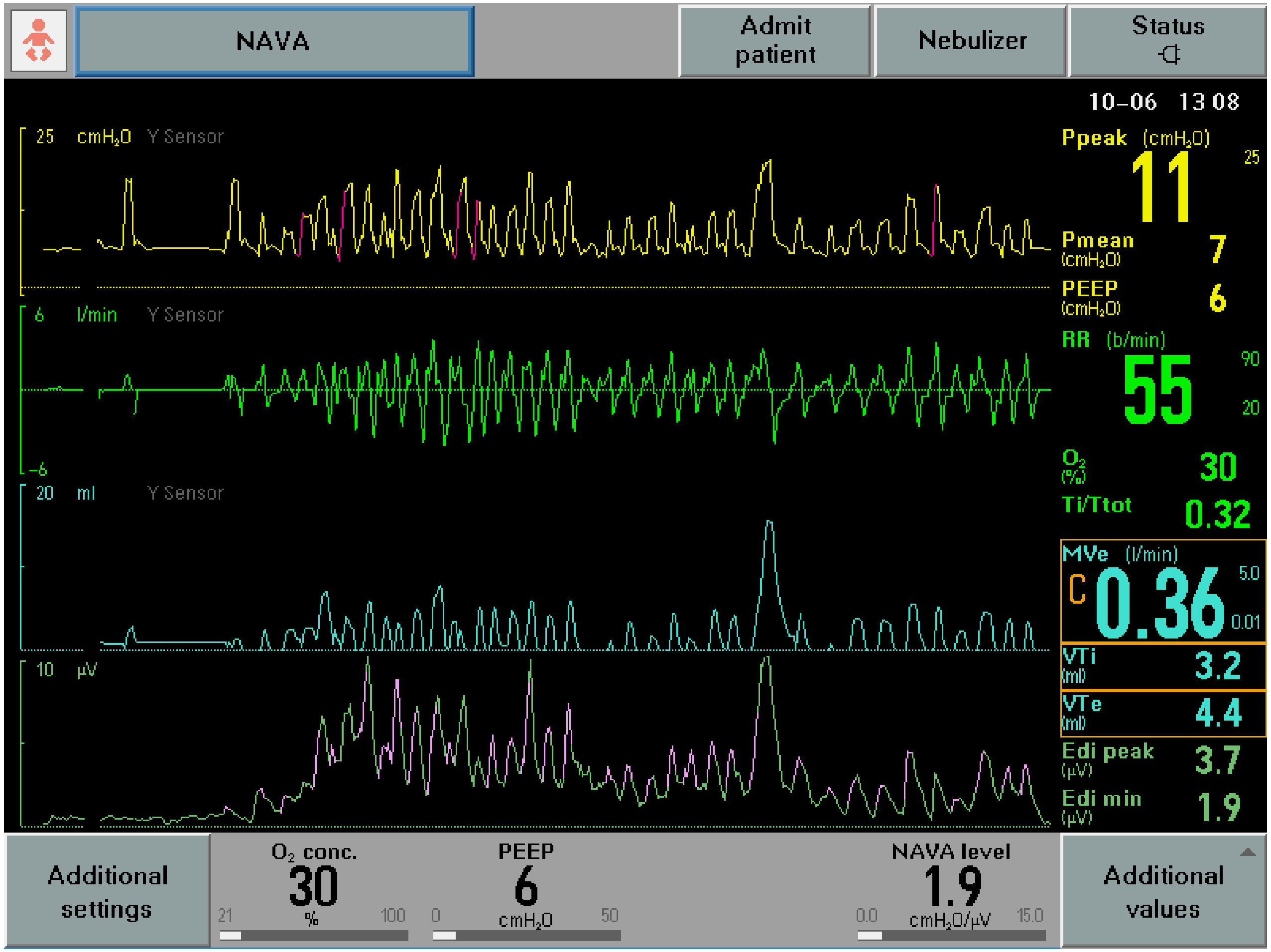
NAVA in the preterm

Pvent

Flow

Tidal volume

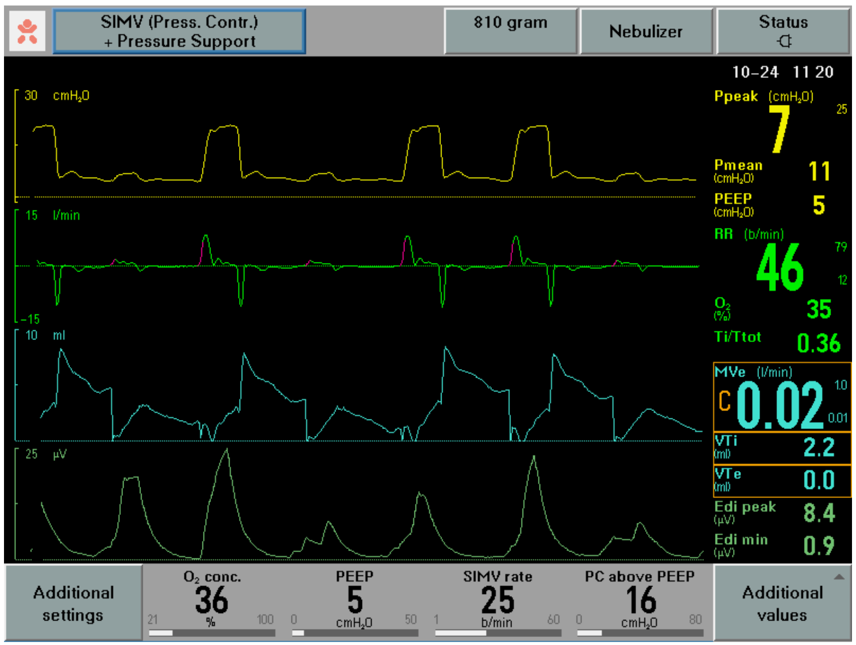
Edi



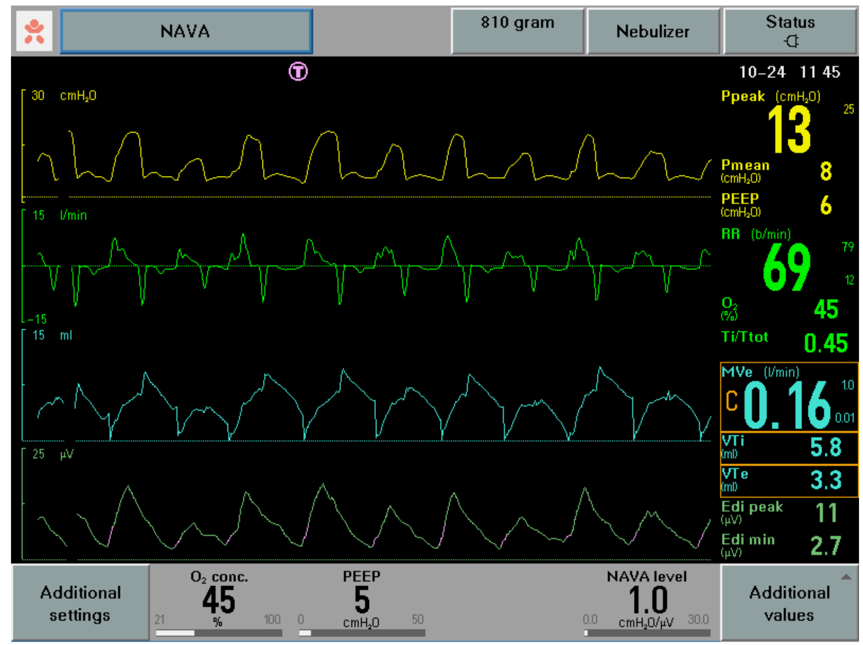
with permission, E Bancalari Jackson Memorial University of Miami

NAVA improves synchrony (810 g)

SIMV



NAVA



Slide Courtesy of H Stein, Toledo Children's Hosp.

Neurally adjusted ventilatory assist improves patient–ventilator interaction in infants as compared with conventional ventilation

Alice Bordessoule[1], Guillaume Emeriaud[1], Sylvain Morneau[1], Philippe Jouvet[1] and Jennifer Beck[2,3]

Pediatric RESEARCH Volume 72 | Number 2 | August 2012

Table 3. Patient–ventilator interaction and respiratory variability

	NAVA	PCV	PSV	*P* value[a]
Patient–ventilator interaction				
Trigger delay (ms)	93 (20)	193 (87)	135 (29)	$P < 0.001$ – PCV vs. NAVA and PSV vs. NAVA
Cycling-off delay (ms)	17 (13)	12 (176)	−77 (81)	NS
→ Asynchrony index (%)	11 (3)	24 (11)	25 (9)	$P < 0.001$ – PCV vs. NAVA and PSV vs. NAVA
→ Wasted efforts (%)	0 (0)	4.3 (4.6)	6.5 (7.7)	$P < 0.05$ – PSV vs. NAVA
→ Percentage of breaths cycled off too early (%)	0.3 (0.4)	12 (13)	21 (19)	$P < 0.01$ – PCV vs. NAVA and PSV vs. NAVA
Correlation between peak Pvent and peak EAdi				
Determination coefficient R2	0.71 (0.22)	0.15 (0.16)	0.12 (0.12)	$P < 0.001$ – PCV vs. NAVA and PSV vs. NAVA
Slope	1.45 (1.5)	0.07 (0.1)	0.06 (0.04)	$P < 0.01$ – PCV vs. NAVA and PSV vs. NAVA
Respiratory variability				
→ Peak Edi – CV (%)	49 (27)	50 (29)	51 (32)	NS
Tidal volume – CV (%)	31 (26)	15 (12)	20 (15)	$P = 0.17$
→ Peak Pvent – CV (%)	24 (8)	2 (1)	2 (2)	$P < 0.01$ – PCV vs. NAVA and PSV vs. NAVA

Means (SD) are presented.

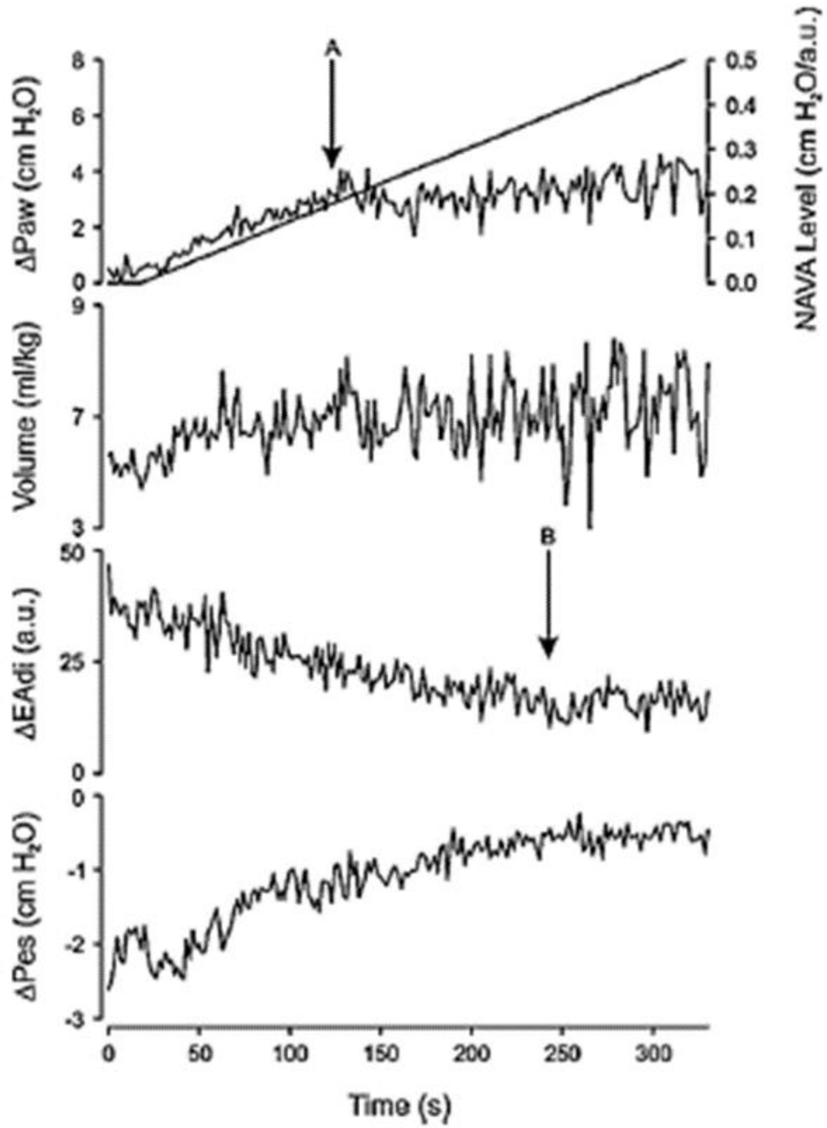
N = 10
Mean weight = 4.3 kg
Mean age = 2 mos
GA at birth: 26 wks

- 22 studies (PUBMED) in 305 patients of all ages have shown that NAVA improves synchrony compared to conventional ventilation modes
- 19 studies in 291 patients of all ages report improved or equivalent physiological parameters

Impact of improved synchrony with NAVA (vs. Conv)

- Improved sleep (Delisle 2011)
- Improved COMFORT (less distress) (De Oliva 2012)
- Less central apnea (Mally 2013 PAS 2013; Delisle 2013)
- Tendency for less sedation (Allander 2013, ESPNIC 2013)
- Equivalent or improved blood gases (n>5 for improvement, rest equivalent when measured)
- More efficient ventilation (less P required) (n>13 studies)
- Less work of breathing to trigger (Spahija 2010, Clement 2011)
- Improved variability of delivered assist and Vt (n=>3)
- Improved lung aeration (Blankman 2013)

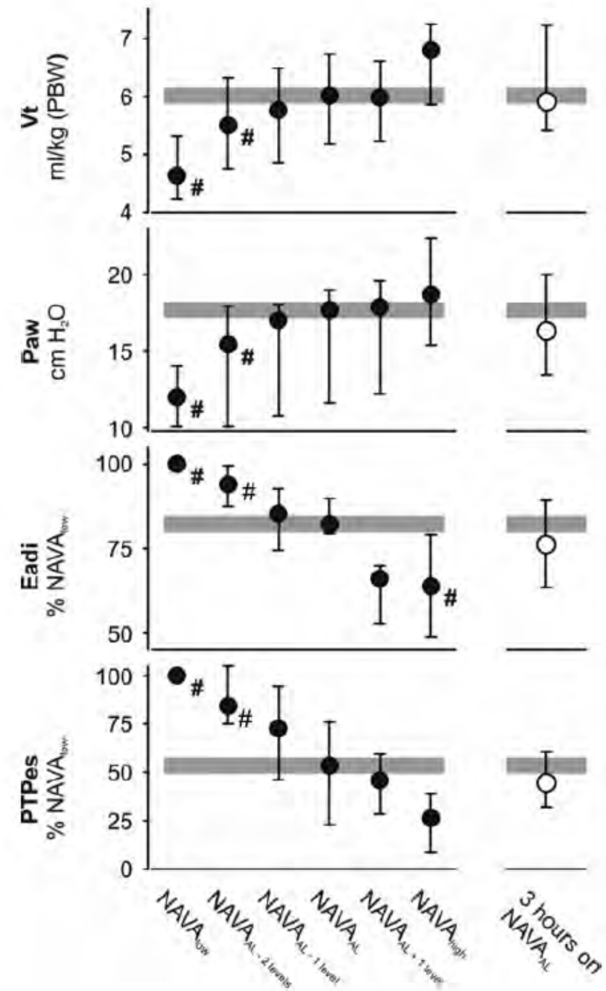
NAVA Can Prevent Over-Assist



Lecomte, Respir Physiology 2009

Titration and Implementation of Neurally Adjusted Ventilatory Assist in Critically Ill Patients*

Lukas Brander, MD; Howard Leong-Poi, MD; Jennifer Beck, PhD; Fabrice Brunet, MD; Stuart J. Hutchison, MD; Arthur S. Slutsky, MD; and Christer Sinderby, PhD



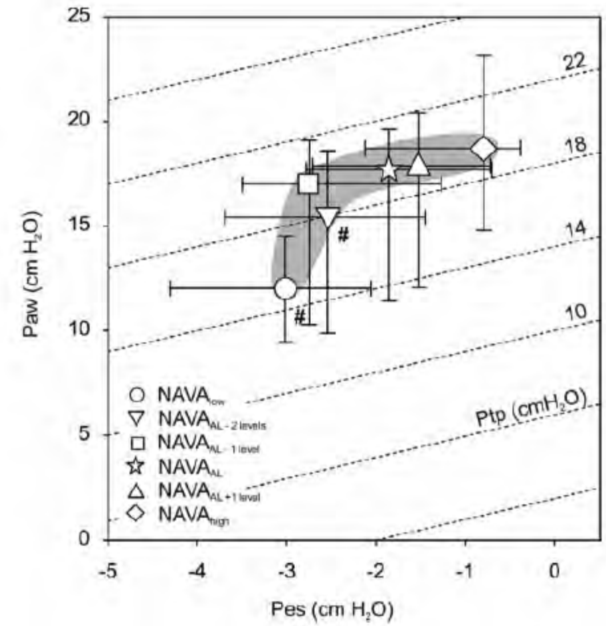


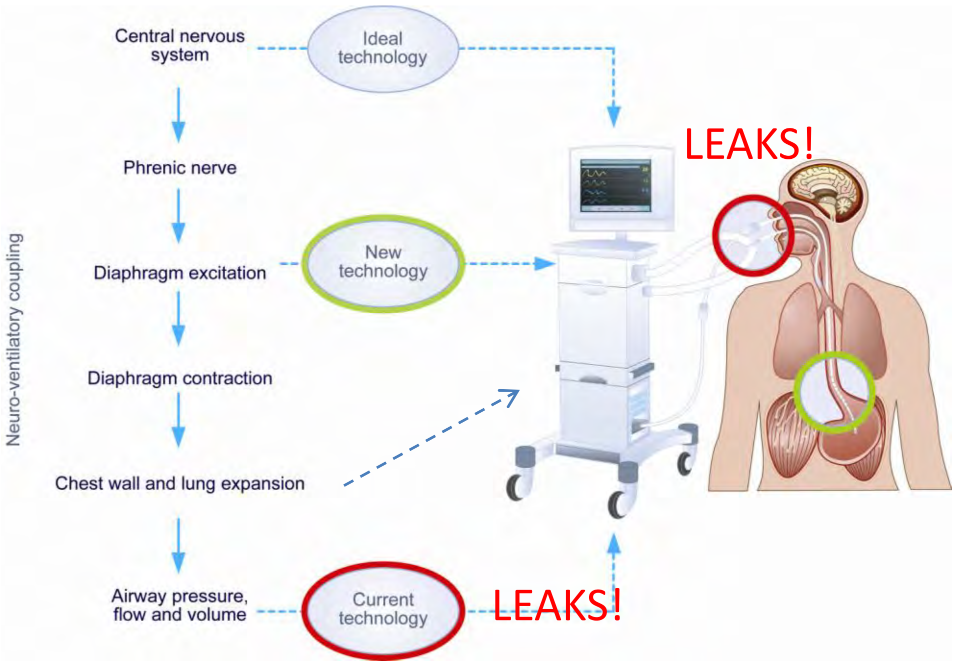
FIGURE 3. Group data for the interaction among mean inspiratory Paw including PEEP, Pes, and Ptp during the NAVA level titration. From NAVAlow to one level below NAVAal (NAVAal-1 level), Paw increased by 5.0 cm H_2O and reduced the Pes deflection by 0.5 cm H_2O such that Ptp increased by 4.5 cm H_2O. Further increasing the NAVA level from NAVAal to NAVAhigh resulted in changes of Paw and Pes that were similar in magnitude (Paw increased by 1.7 cm H_2O and Pes decreased by 1.95 cm H_2O, respectively) and hence in a essentially unaltered Ptp. The PEEP was 8.5 cm H_2O (quartiles, 5.3 to 11.8 cm H_2O) and remained unchanged during the NAVA level titration. Abbreviations are the same as for Figure 2. Symbols represent group median, lines indicate the 25th and 75th percentiles. # = $p < 0.05$ vs NAVAal.

- 7 studies in 100 patients show down-regulation of Edi with increasing NAVA

- 14 studies in 201 adults on NAVA show mean Vt 6.9 ml/kg, rr 24 bpm

- 13 studies in 197 infants on NAVA show mean Vt 6.3 ml/kg, rr 45 bpm

Factors Affecting NIV



- Controller signal for patient-ventilator synchrony
- Inadequate (pneumatic) monitoring
- Properties of interface
  - Masks and prongs (leaks)
  - Prongs (resistance)
- Leaks and pressure delivery
- Upper airways (protection and control of FRC)

From Principles and Practice of Mechanical Ventilation, ed. M Tobin, 2012

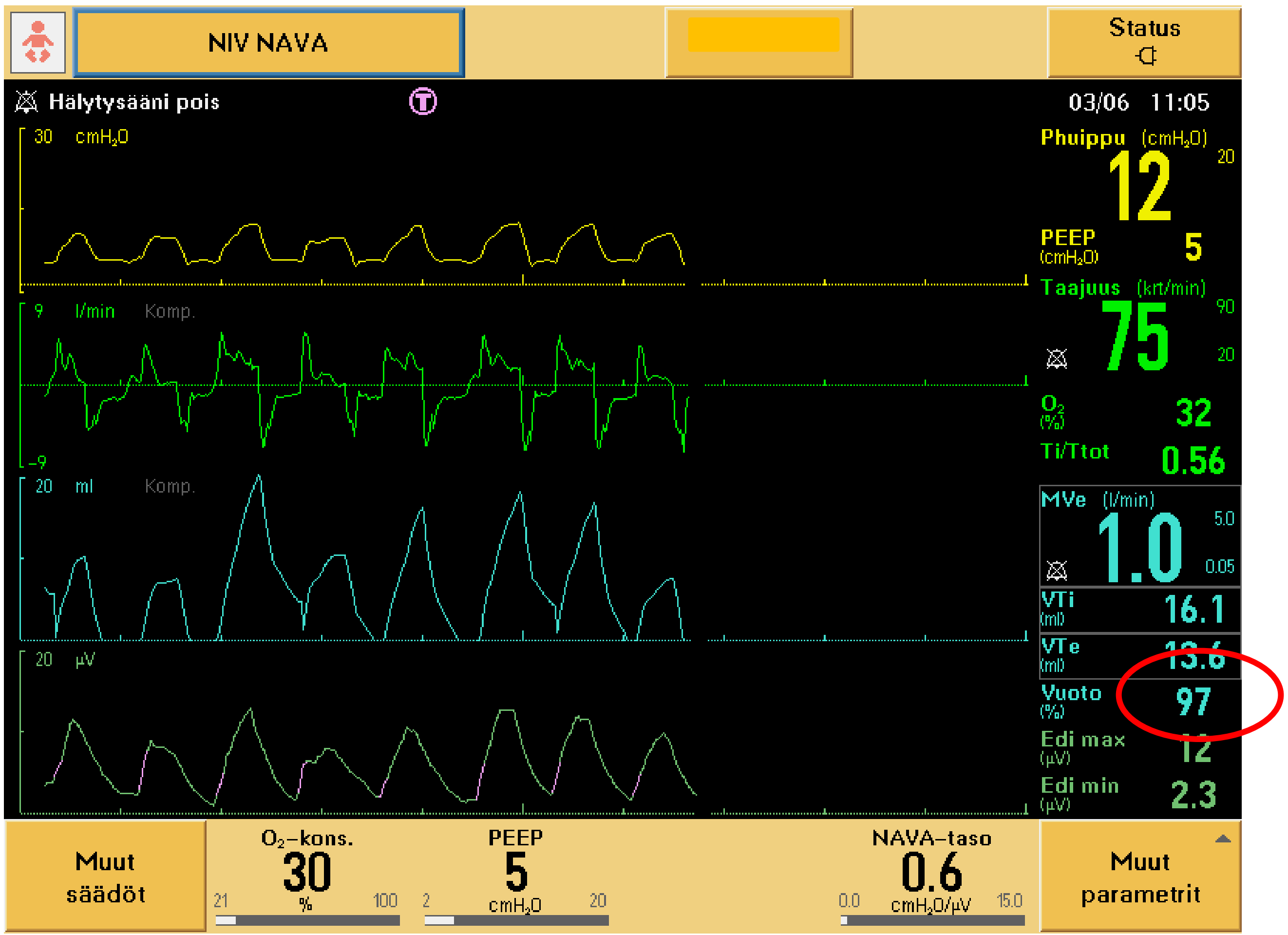
NIV-NAVA in the preterm

Pvent

Flow

Vol

EAdi



Slide courtesy of Dr. Lehtonen (Turku University Hospital)

0031-3998/09/6506-0663
PEDIATRIC RESEARCH

Vol. 65, No. 6, 2009
Printed in U.S.A.

Patient-Ventilator Interaction During Neurally Adjusted Ventilatory Assist in Low Birth Weight Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASSELLI, LUCIA MIRABELLA, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER SINDERBY

Table 2. *Vital signs, ventilator parameters, neural breathing pattern, and patient-ventilator interaction*

	Conventional ventilation	NAVA-intubated	NAVA-extubated	*p*
	n = 7	*n* = 7	*n* = 5	
F_{IO_2} (%)	25.1 (5.8)†	26.4 (5.9)*	38.0 (19.1)	0.0034
S_{AO_2} (%)	94.6 (2.7)	94.1 (3.5)	95.4 (6.5)	0.961
T_{CO_2} (mm hg)	53.4 (14.6)	52.6 (13.0)	60.6 (12.5)	0.787
Heart rate (per min)	160 (15)	159 (11)	166 (11)	0.868
	n = 5	*n* = 7	*n* = 5	
MAPi (cm H_2O)	12.5 (1.5)*	9.6 (1.8)*	5.5 (1.6)	0.002
ΔPi (cm H_2O)	9.3 (1.3)	9.9 (1.3)	9.4 (3.1)	0.710
EAdi phasic (au)	27.9 (19.5)	43.6 (18.7)	44.8 (32.4)	0.333
EAdi tonic (au)	5.5 (2.0)	4.7 (3.0)	4.7 (1.4)	0.157
Nti (msec)	258 (43)	406 (131)	436 (198)	0.09
Nte (msec)	712 (139)	875 (237)†	1001 (256)	0.044
Nrr (per min)	74 (7)	54 (14)†	51 (14)†	0.004
EAdi-time product (au*s/min)	556.4 (421.2)	823.4 (444.3)	670.2 (524.5)	0.504
Trigger delay (ms)	74 (17)	72 (23)	76 (33)	0.698
Cycling-off delay (ms)	−120 (66)	32 (34)†	28 (11)†	<0.001
R^2 for EAdi *vs* Pvent	0.08 (0.1)	0.80 (0.06)†	0.73 (22)†	<0.001
Slope EAdi *vs* Pvent (cm H_2O per au)	0 (0.01)	0.19 (0.1)†	0.2 (0.1)†	0.007

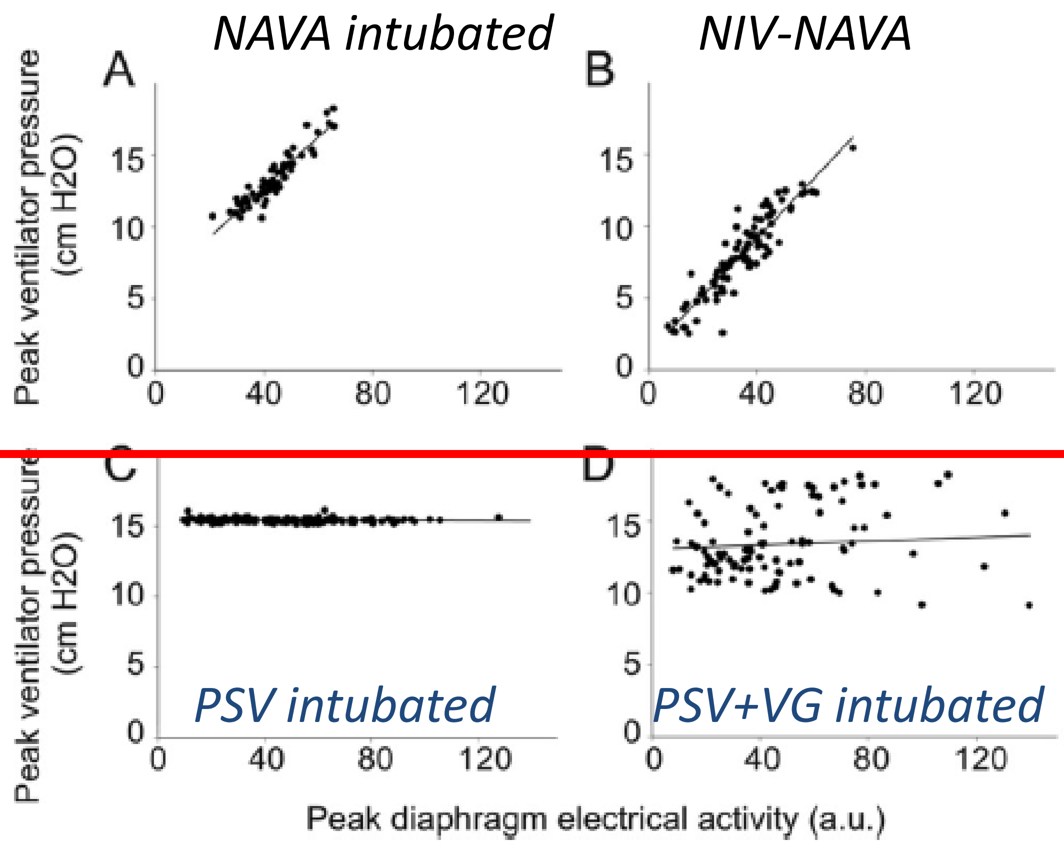
* Statistically different from NAVA-ext.

† Statistically different from Conv.

F_{IO_2}, fraction of inspired oxygen; S_{AO_2}, oxygen saturation; T_{CO_2}, transcutaneous carbon dioxide; MAPi, mean inspiratory airway pressure; ΔPi, delta inspiratory pressure above PEEP; EAdi, electrical activity of the diaphragm; Nti, neural inspiratory time; Nte, neural expiratory time; Nrr, neural respiratory rate; R^2, determination coefficient; Pvent, ventilator delivered pressure.

Beck et al, 2009 Ped Res

Proportionality between patient effort and ventilatory assist



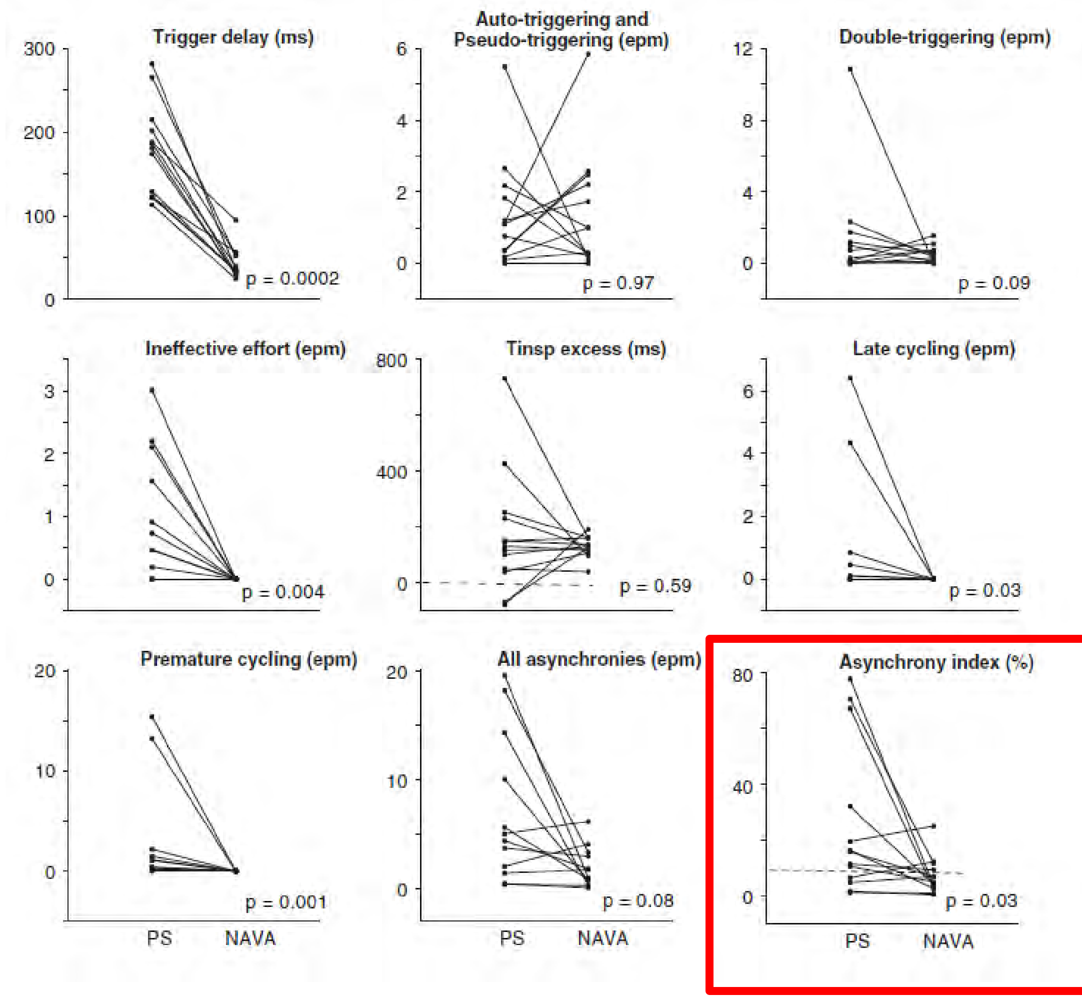
Beck et al, Ped Res 2009

Intensive Care Med
DOI 10.1007/s00134-012-2626-9

ORIGINAL

Lise Piquilloud
Didier Tassaux
Emilie Bialais
Bernard Lambermont
Thierry Sottiaux
Jean Roeseler
Pierre-François Laterre
Philippe Jolliet
Jean-Pierre Revelly

Neurally adjusted ventilatory assist (NAVA) improves patient–ventilator interaction during non-invasive ventilation delivered by face mask



N= 13 Adult ICU (incl 2 COPD)
20 min NIV0NAVA, 20 MIN NIV PSV
Mask

Patient–Ventilator Asynchrony During Noninvasive Pressure Support Ventilation and Neurally Adjusted Ventilatory Assist in Infants and Children

PCCM, In Press, June 2013

Laurence Vignaux, PT[1,2]; Serge Grazioli, MD[3]; Lise Piquilloud, MD[4]; Nathalie Bochaton[3]; Oliver Karam, MD[3]; Yann Levy-Jamet[3]; Thomas Jaecklin, MD[3]; Pierre Tourneux, MD, PhD[2,5]; Philippe Jolliet, MD[4]; Peter C. Rimensberger, MD, PhD[3]

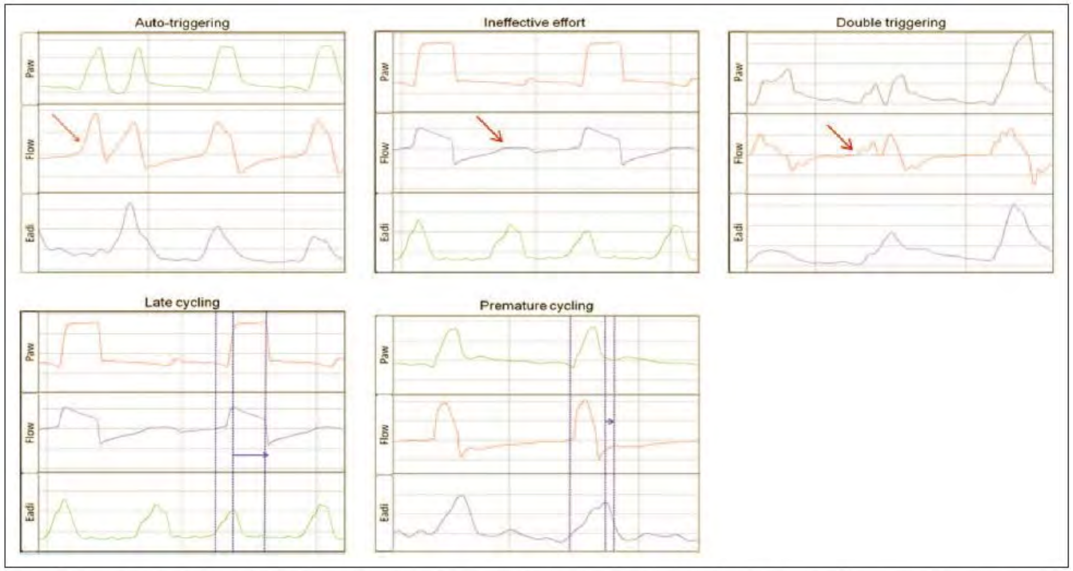


Figure 2. Representative tracings of the five types of asynchrony. Eadi = electrical activity of the diaphragm tracing, Paw= airway pressure, flow = instantaneous flow. *Downward pointing arrows* indicate relevant events.

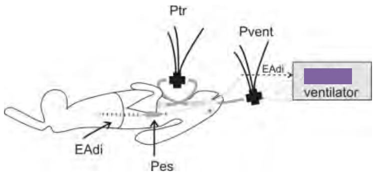
N=6
Consecutive, requiring NIV for ARF
Age: 18 mos
Weight: 8 kg
Mask (4) or prongs (2)

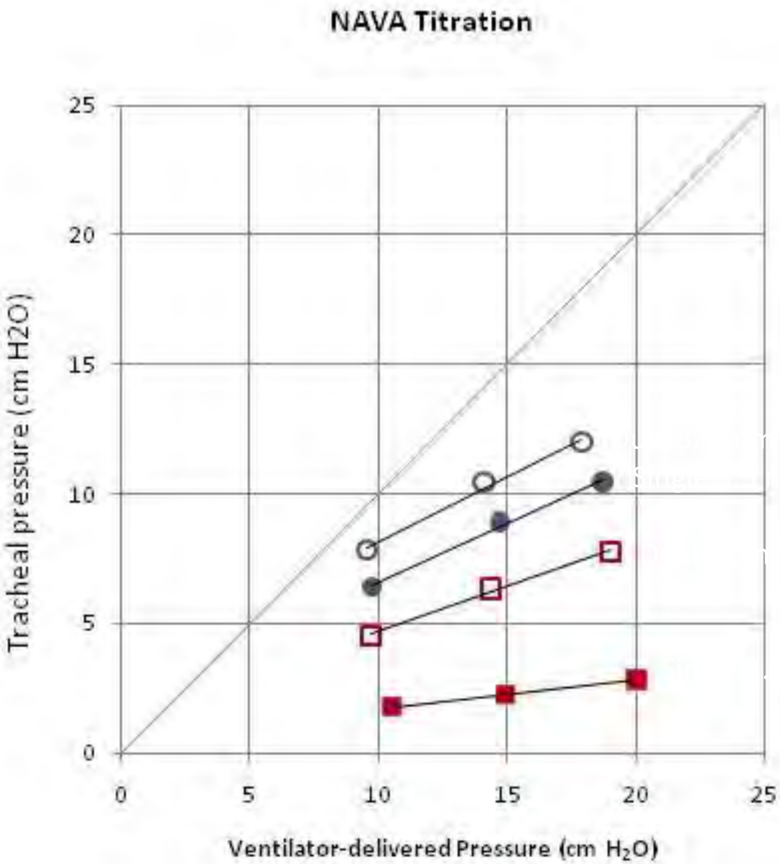
TABLE 2. Number and Type of Asynchronies ($n = 6$)

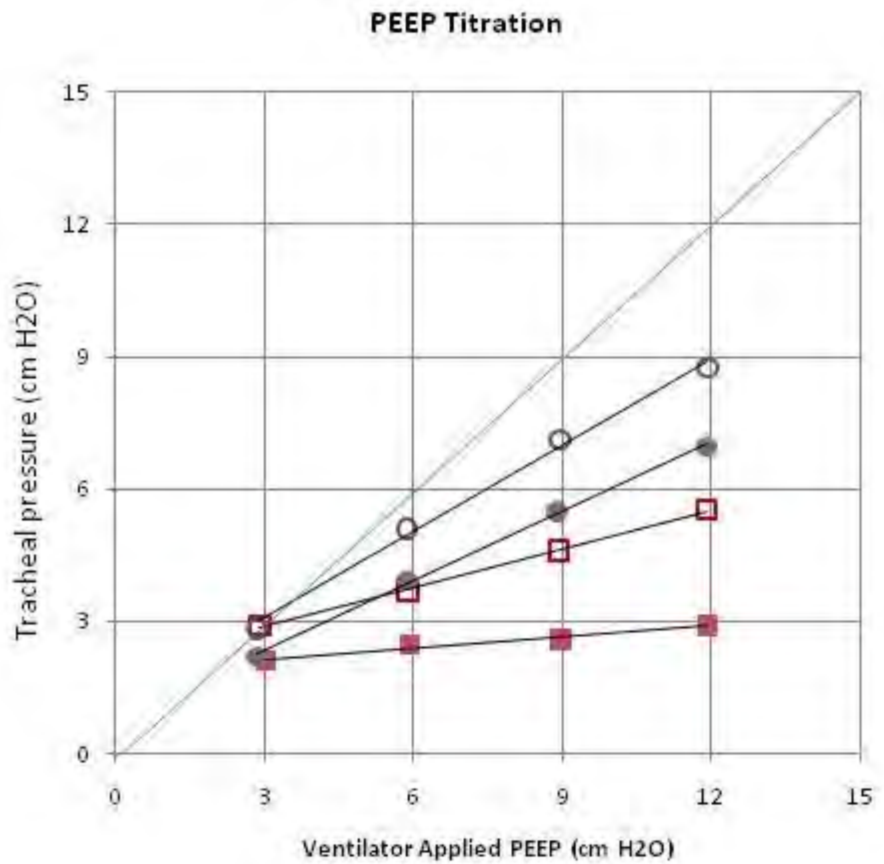
	PSinit	PSbest	NAVA	*p* Analysis of Variance	*p* NAVA vs PSinit	*p* NAVA vs PSbest	*p* PSbest vs PSinit
Autotriggering (*n*/min)	4.8 (1.7–12)	4.7 (1.3–7)	0.2 (0–0.9)	0.083	–	–	–
Ineffective efforts (*n*/min)	9.9 (1.7–18)	5.1 (1–15.6)	0 (0–0)	0.029	<0.05	NS	<0.05
Double triggering (*n*/min)	0.2 (0.1–0.3)	0 (0–0.8)	0.7 (0.2–1.7)	0.120	–	–	–
Late cycling (*n*/min)	0.5 (0.1–1.7)	0 (0–0.8)	0 (0–0.2)	0.430	–	–	–
Premature cycling (*n*/min)	6.3 (3.2–18.7)	3.4 (1.1–7.7)	0 (0–0)	0.022	<0.05	NS	NS
Asynchrony index (%)	65.5 (42–76)	40 (28–65)	2.3 (0.7–5)	<0.001	<0.05	<0.05	NS

PS = pressure support, PSinit = mode in pressure support with initial adjustment of the cycling criterion, PSbest = mode in pressure support with the cycling criterion that allowed the best results of asynchrony, NAVA = neurally adjusted ventilatory assist.
Values are expressed in median (25th–75th percentile).

Effect of nasal prongs on pressure delivery (n=10)







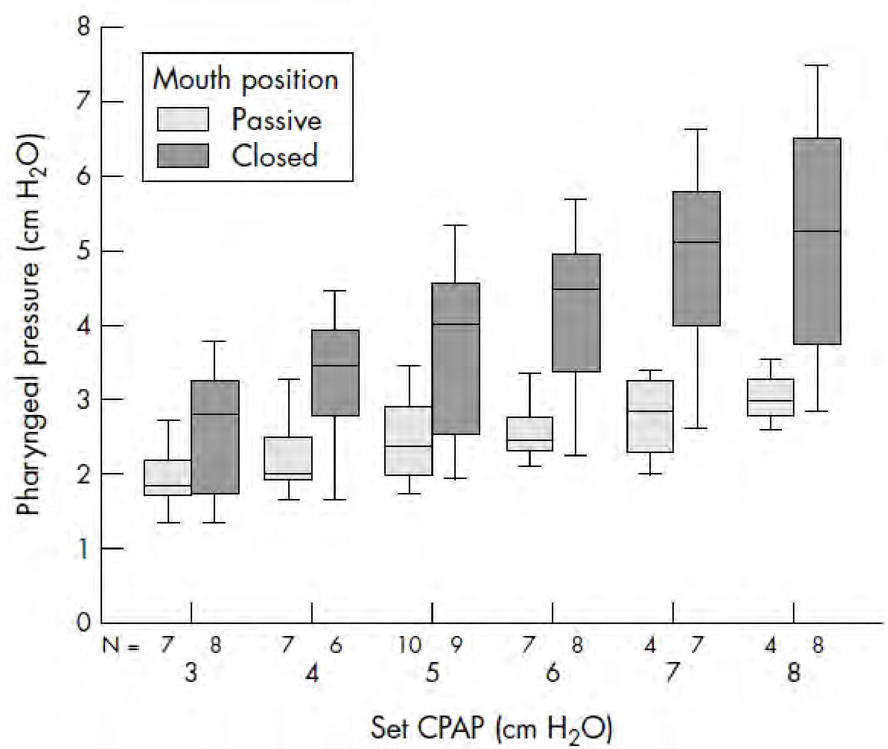
Beck et al (ATS 2010)

SHORT REPORT

Pharyngeal pressure in preterm infants receiving nasal continuous positive airway pressure

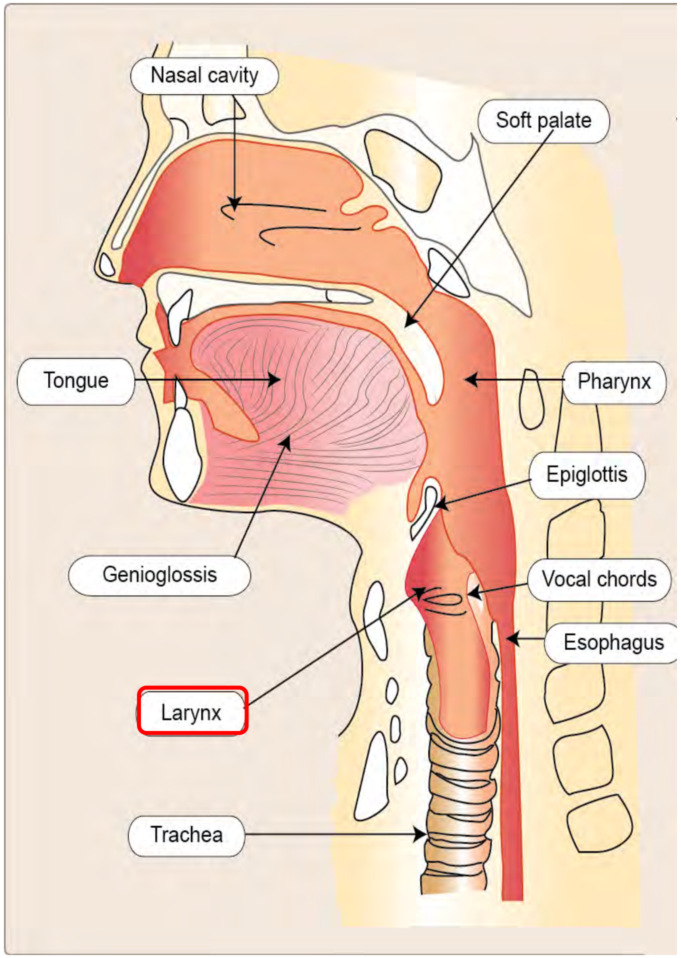
A G De Paoli, R Lau, P G Davis, C J Morley

Arch Dis Child Fetal Neonatal Ed 2005;**90**:F79–F81. doi: 10.1136/adc.2004.052274



N= 11 preterms
Binasal Hudson prongs
Bubble cpap

Upper Airways

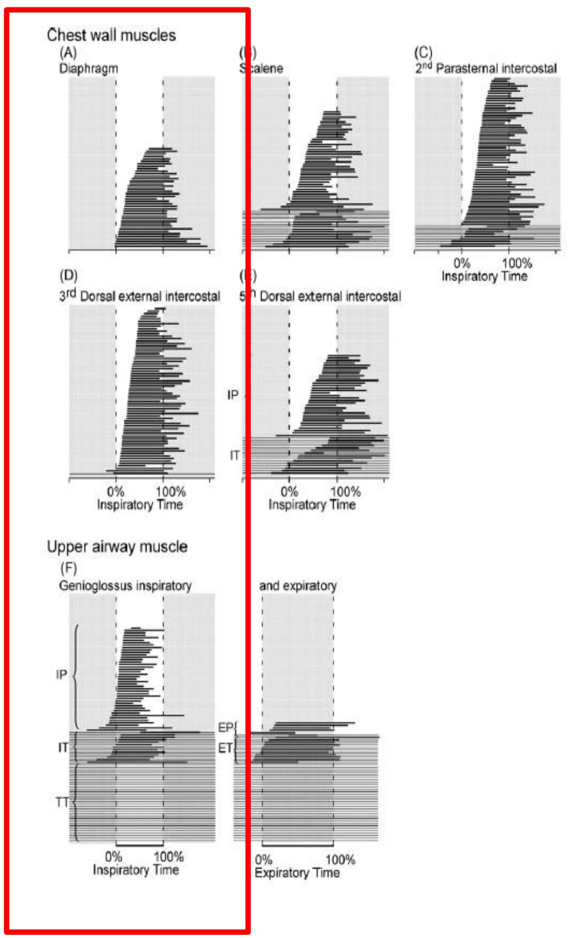


Role:

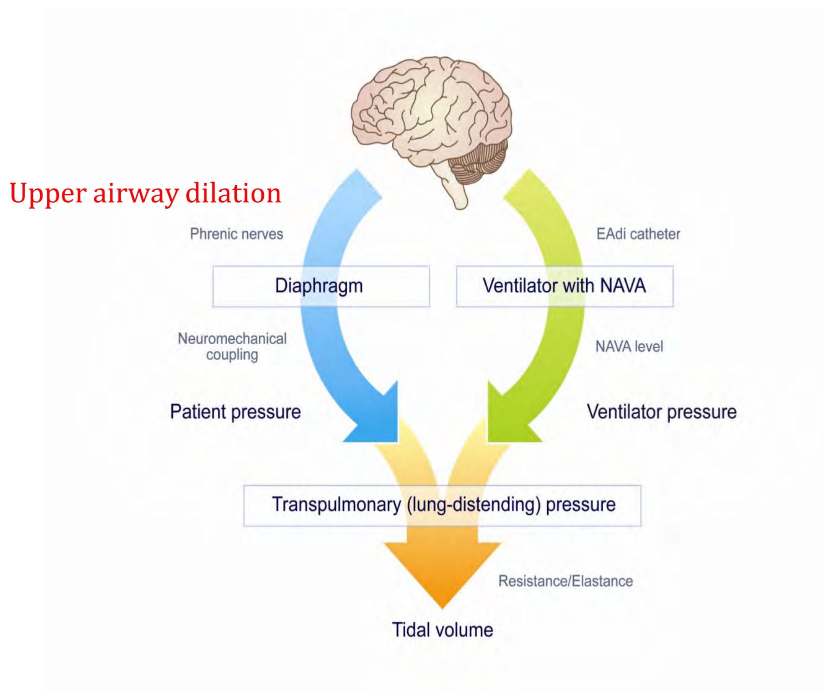
- Humidification
- Speech
- Swallowing
- Airway protection
- Airway dilation for inspiration
- Braking of expiratory flow to maintain EELV

Maquet Clinical Image Collection

Timing of Activation of Upper Airways



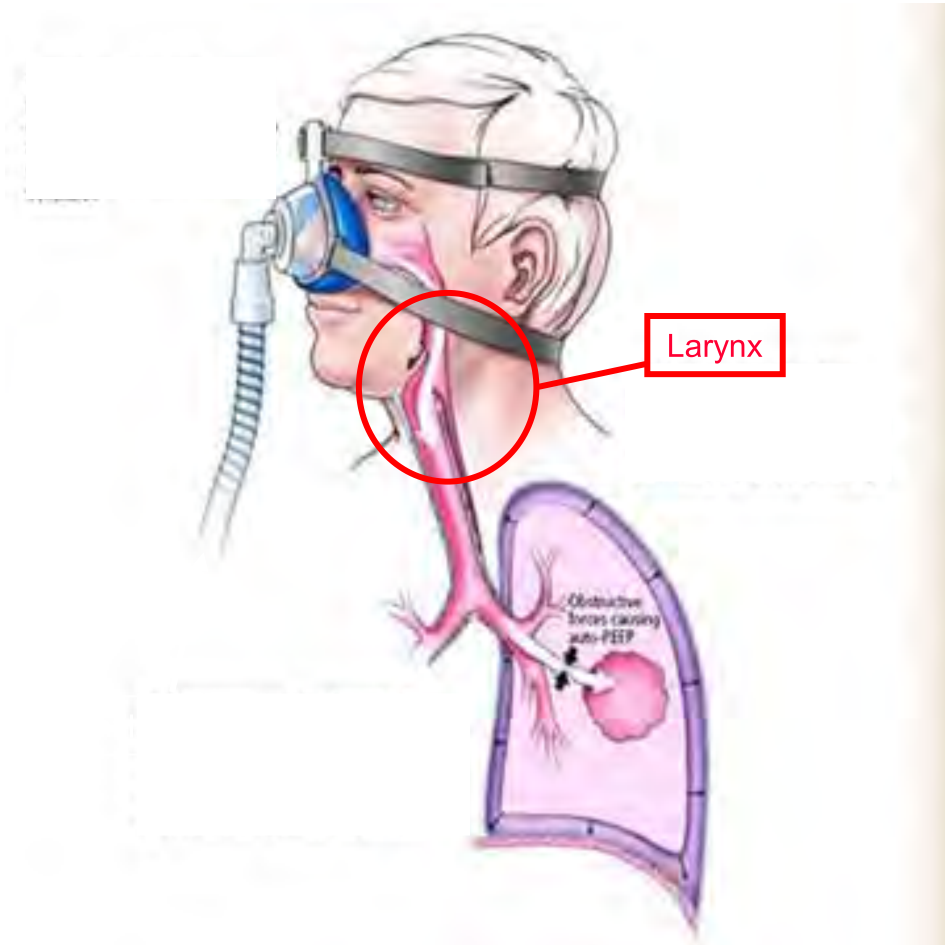
Butler Respir Physiol Neurobiol 2007



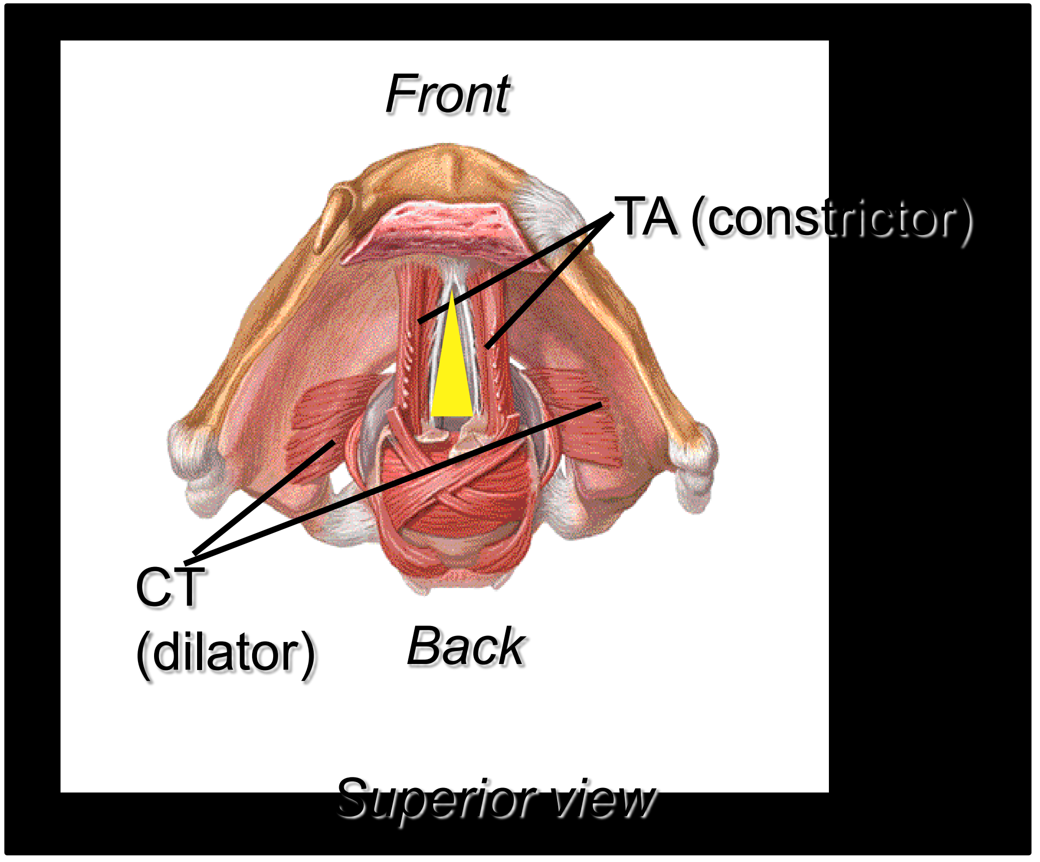
Principles and Practice of Mechanical Ventilation, M Tobin Ed.

Larynx and NIV

- Larynx = a closing valve
- Original function = to defend the lower airways against potentially harmful intruders



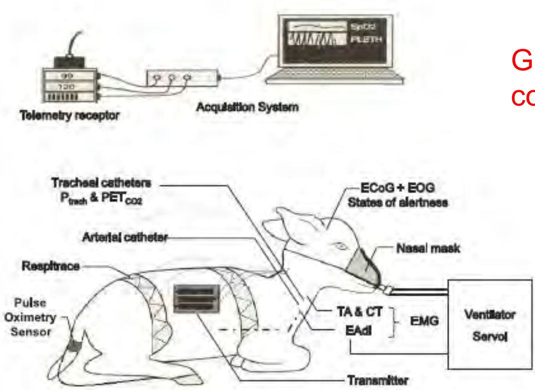
Important Laryngeal Muscles

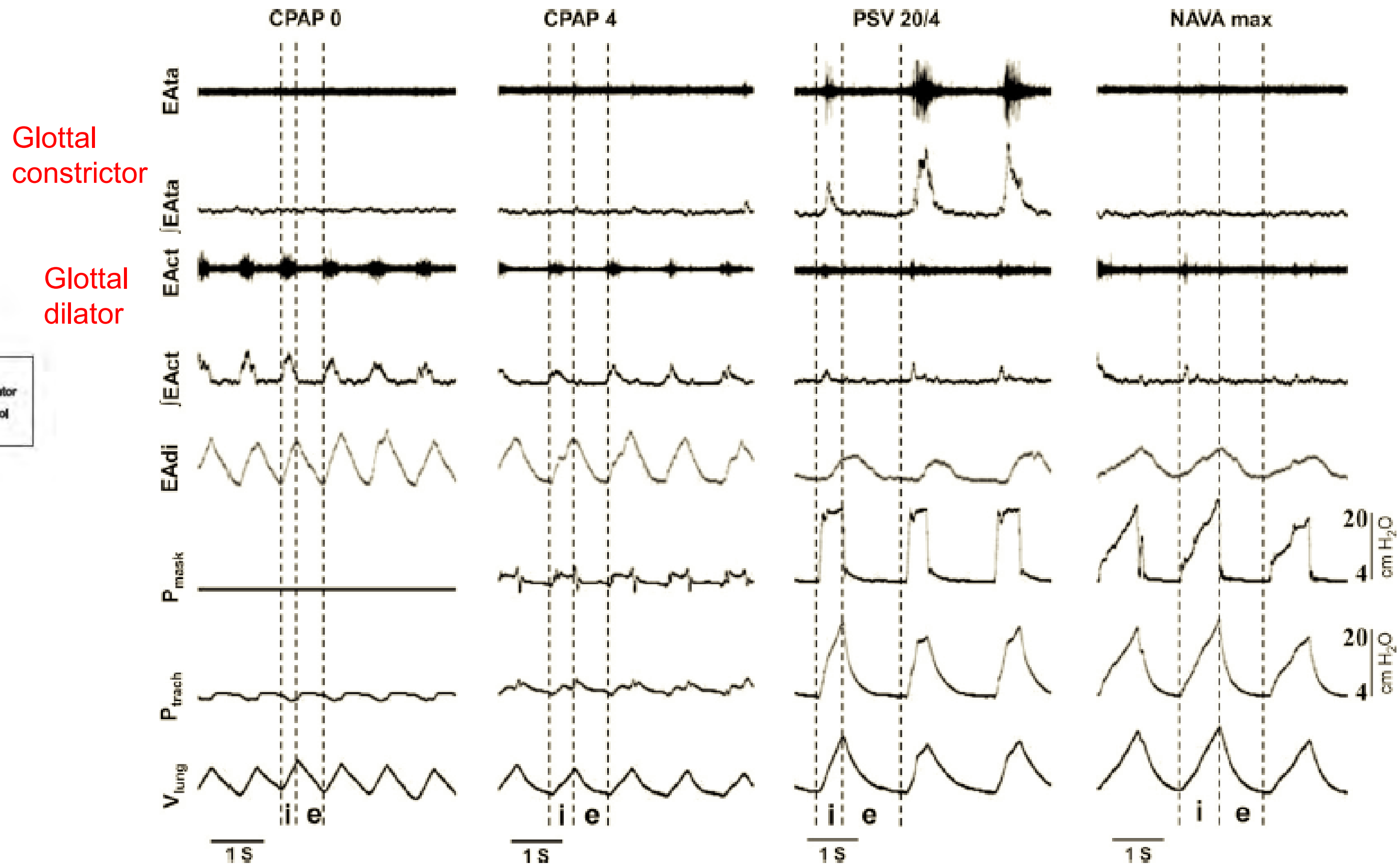


J Appl Physiol 113: 63–70, 2012.
First published April 19, 2012; doi:10.1152/japplphysiol.01496.2011.

Absence of inspiratory laryngeal constrictor muscle activity during nasal neurally adjusted ventilatory assist in newborn lambs

Mohamed Amine Hadj-Ahmed,[1] Nathalie Samson,[1] Marie Bussières,[2] Jennifer Beck,[3] and Jean-Paul Praud[1,2]





Summary

- The Edi is a physiological signal representative of central respiratory output
- The Edi is normally present in spontaneously breathing subjects. The waveform has a characteristic cyclic/phasic pattern with quantifiable measures of amplitude and timing.
- The Edi is essentially a vital sign, just like the electrocardiogram.
- With Edi monitoring, clinicians can answer these questions:
  - Is my patient breathing?
  - Is my patient synchronous with the ventilator?
  - Is my treatment/intervention helping?
  - Is it a central or obstructive apnea?
- NAVA provides synchronized and proportional assist (invasive and non-invasive)
- Ventilator becomes a second respiratory muscle and is therefore a slave to the patient's own protective reflexes and control of breathing responses